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EVALUATION OF SET 45 MAGNESIUM PHOSPHATE CONCRETE FOR USE IN CONSTRUCTING TOWER PADS

Report No. 88-67-K

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ABSTRACT

This report summarizes the research investigation undertaken to assess Set 45 magnesium phosphate concrete as a bearing pad material for transmission line construction at low temperatures (10° to -20°C). Laboratory tests were carried out to determine the physical characteristics of this material when subjected to various environments. The results of this program identify major deficiences in the product and as such the material is not recommended for use.

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To Mr. J.D. Forsyth
Transmission Line Projects
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Attn: Mr. J.L. Phillips

EVALUATION OF SET 45 MAGNESIUM PHOSPHATE
CONCRETE FOR USE IN CONSTRUCTING TOWER PADS

1.0 INTRODUCTION

A limited investigation was carried out to evaluate the physical characteristics of Set 45 magnesium phosphate concrete for use in bearing pad construction at low temperatures (10° to -20°C). Part of this investigation included carrying out full-scale field trials. This report summarizes the results of the above work. Information on the results has been previously given to the S&T Programs group.

2.0 LABORATORY STUDIES

Initially the physical characteristics of Set 45 were determined as outlined below:

Flowability 75x150 mm Open End Cylinder	Temperature Rise&Initial Setting Time Using Various Size Specimens	Plastic Volume Shrinkage CAN3-A23.2	Compressive Strength, Density & Modulus of Rupture ASTM C 39/ C 78	Thermal Coefficient of Expansion ASTM C 531	Freeze-Thaw Resistance ASTM C 666 Procedure A
X/1/	X/1/	X/1/	X/2/	X	X

/1/ Test carried out at +10°, -5° and -20°C
/2/ Same as /1/ above, except that Density and Modulus of Rupture were done at 23°C.

The various tests are outlined in Appendix A.

These characteristics were observed by conditioning, mixing, placing, curing and testing all materials at the required test temperature. At the -5°C and -20°C temperatures, Set 45 was initially mixed using 15°C water.

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2.1 Results

The results of these tests are summarized in Tables 1 to 3 and Figures 1 to 3. The tests generally indicate that Set 45 provided the necessary physical characteristics as follows, when used in thicknesses of up to 18":

a) The material set at low temperatures (ie, less than 2 hr at -20°C) when used in a large enough mass (12" x 12" x 18"). Temperatures in excess of 50°C were measured during the initial hydration of the product (Figures 1 and 2).

b) Specimens (3" x 6" cylinders and 2" cubes) made from Set 45 exhibited rapid strength gain and high ultimate strengths in compression (ie, greater than 6000 psi) at temperatures of +10° and -5°C (Table 2). At -20°C, the smaller specimens froze (Figure 1) and developed very little strength, if any; however, when used in large enough masses (ie, 12" x 12" x 18" pads) strengths of 6000 psi were measured.

c) Shrinkage was minimal (ie, 0.2%) and comparable to a Portland cement concrete (Table 1).

d) Thermal coefficient of expansion, modulus of rupture and density were comparable to a good quality Portland cement concrete (Table 3).

e) Freeze-thaw testing in a highly saturated condition indicated a potential durability problem (ie, durability factor of 27.8 after 168 freeze-thaw cycles, Table 3). Because of this, the material was being considered for use in above ground applications where bearing pads would not become saturated for extended periods of time.

3.0 FIELD STUDIES

A subsequent request was received from S&T Programs to use Set 45 in large masses for constructing tower leg pads. As a result, two pads 3-1/2 ft in diameter and approximately 6 ft high were constructed in the field under ambient temperature conditions which varied from -1° to -10°C. Pad 2 was made with neat Set 45, while Pad 1 was made with 3/8" coarse aggregate in the mix.

Construction of Pads - The pads were constructed to simulate actual field conditions. The rock surface was mechanically cleaned and holes were drilled to anchor the reinforcing steel into the rock. Thermocouple wires were installed at various elevations to monitor the temperature rise (Figure 4). After installing the thermocouple wires, 'Sonotube' formwork was positioned (Figure 5).

3.1 Mixing of Set 45

All batches of concrete were mixed using a 5 cu ft drum mixer (Figure 6). The amounts of water used to mix Set 45 are shown below:

Pad 1	Neat Set 45 + 3/8" Agg	Water per 22.7 kg bag - 1.9 to 2.1 L
Pad 2	Neat Set 45	Water per 22.7 kg bag - 1.9 to 2.0 L

The concrete was mixed as follows:

a) Approximately 60% of the water was added to the mixer first (Figure 6).

b) Set 45 material was then added, followed by the addition of the 3/8" aggregate (Pad 1) and the remaining water.

c) The material was then mixed for a minimum of 5 minutes. A flowable concrete was produced (Figure 7).

All mixing and placing of the concrete was carried out under the supervision of the manufacturer.

The Set 45 concrete was discharged from the mixer onto a chute and into the form (Figure 7). The concrete was self levelling and required no vibration. No segregation of the concrete occurred during placing.

3.2 Results

Pad 1 - A total of 88 bags of Set 45 and 44 bags of 3/8" silica aggregate were used to construct this pad. Details of the batch sizes, ambient temperature, material temperature, etc. are included in Table B1 (B1, B2, etc. refer to Appendix B). The form was filled in 1 hour and 33 minutes. The quantity of grout placed with time is shown in Figure B1. The average temperature of the concrete mix ingredients prior to and that of concrete after mixing was as follows:

Set 45 - 0°C
3/8" Aggregate - 2°C
Water - 6°C
Mixed Concrete - 4°C

The location of the thermocouple wires to monitor the temperature of the concrete is shown in Figure B2. The temperature rise of the concrete at various locations is shown in Figure B3. The peak temperature measured at the center of the pad and near the top of the pad was 65°C. The maximum measured temperatures at other locations in the pad are shown in Figure B4. The setting characteristics of the concrete at various depths are shown in Figure B5. The base concrete started to set within 65 minutes after placing.

Pad 2 - A total of 112 bags of Set 45 were used to construct this pad. Details of the batch sizes, ambient temperature, material temperature, etc. are included in Table B2. The form was filled in 1 hour and 17 minutes. The quantity of grout placed with time is shown in Figure B1. The average temperature of the concrete mix ingredients prior to and that of concrete after mixing was as follows:

Set 45 - 1°C
Water - 10°C
Mixed Concrete - 3°C

The location of the thermocouple wires to monitor the temperature development of the concrete is shown in Figure B6. The peak temperatures measured at the center of the pad was 90°C (Figure B7). The maximum measured temperatures at other locations are shown in Figures B8. The setting characteristics of the grout at various depths are shown in Figure B5. The base concrete started to set within 70 minutes of placing the concrete.

A comparison between the maximum temperature rise of Pads 1 and 2 is shown in Figure B9. A view of the hardened concrete is shown in Figure B10.

3.3 Assessment of Physical Characteristics

Subsequent to casting these pads, 100 mm diameter cores were obtained from the test pads to determine the quality of the in-situ concrete. The density, water absorption and compressive strength were determined. The results are shown in Figure B11 to B13, and the following observations were made:

a) Numerous voids were detected in both pads as a result of ammonia gas produced during the reaction of Set 45.

b) Cores removed from the pad containing coarse aggregate indicate washout of the cement matrix during drilling. Also, bond between the aggregate and cement paste was very poor.

c) Density ranged from 125.5 to 131.8 lbs/ft^3 for the neat Set 45 pad and from 135.0 to 139.2 lbs/ft^3 for the pad containing coarse aggregate. The density of the material increased with depth (Figure B11).

d) Water absorption varied between 7.9% and 8.9% for the neat Set 45 pad and from 10.1% to 11.1% for the pad containing coarse aggregate (Figure B12). For a good quality concrete, it generally varies between approximately 5.0% and 7.0%.

e) Forty-eight day compressive strengths were very low (Pad 1 - 1240 to 1690 psi; Pad 2 - 1420 to 3490 psi). See Figure B13 for results. These low strengths may be due to the high temperature rise and excessive void formation in the concrete. Control cylinders (3" x 6") made in the field developed 5-day strengths of between 2440 (Pad 1) and 4150 (Pad 2) psi.

4.0 FURTHER LABORATORY STUDIES

Since the field test results were very poor and there was some concern with durability, the following additional tests were carried out:

1) Cores were removed from the initial laboratory test blocks and tested as follows:

   a) Compressive strength at 23°C

   b) Compressive strength at 23°C after 24 hours exposure to 100°C

2) X-ray diffraction of Set 45 to identify major constituents

3) Autoclave expansion to identify any unsoundness.

4) Freeze-thaw tests on neat Set 45 and Set 45 with 3/8" aggregate.

4.1 Results

The compressive strength of the cores removed from the initial laboratory test blocks was approximately 6000 psi. However, other cores removed from the same test blocks and exposed to 100°C for 24 hours developed 1/3 of the above compressive strength (ie, 2000 psi). Similar results were observed with the field cores as well. These results are shown in Table B3. These results indicate that high temperature development appears to be detrimental to strength development. There is probably a threshold temperature at which no detrimental effect would occur; however, this was not determined.

The X-ray diffraction showed the material contained significant quantities of periclase (MgO). See Tables B4 and B5. When periclase comes in contact with water, brucite may form which could be detrimental because of the expansive nature. This may be the reason for the disintegration of Set 45 in the autoclave as outlined below.

The results of the autoclave expansion revealed that the material disintegrated (Figure B14). Where measurements could be made, expansion was in excess of 0.8%.

The results of the freeze-thaw tests for both neat Set 45 and the mix containing 3/8" aggregate showed poor durability. Within 50 freeze-thaw cycles the durability factors for all specimens were less than 10 (Table B6 and Figure B15).

5.0 CONCLUSIONS

Contrary to the manufacturer's information, Set 45 appears to have some major problems and therefore is not recommended for use. The poor results might be attributable to the following:

a) Excessive ammonia gas formation in the plastic state during the reaction of the product leading to a porous material.

b) High temperatures during hydration (60 to 90°C) contributed to the degradation of the product. It is apparent from the results that high temperatures (60°C), if short in duration (3-4 hrs), may not be detrimental; however, in large masses, where high temperatures (60 to 90°C) are prominent for a longer period of time during hydration, they could lead to degradation.

c) Subsequent exposure to high temperatures (ie, 100°C) after fully curing the material has led to a strength reduction in excess of 60%.

d) The material has poor freeze-thaw resistance (a durability factor of less than 10) in a highly saturated condition and may be influenced by some of the above factors.

e) It would appear that there may be some concerns in the manufacturing of this product due to possible variation in the quality of the finished product. The initial laboratory studies generally indicated a good quality material; however, the latter field tests showed that the material developed poor physical characteristics.

6.0 REMARKS

The manufacturer was contacted and informed of the above test results. They are in agreement with some of our findings and are presently looking into the problems that have been identified. Some of their analyses to date are included in Appendix C. However, sufficient information to warrant the use of the product has not been obtained to date, and as such the material is not recommended for use.

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TABLE 1

PHYSICAL CHARACTERISTICS OF SET 45

MATERIAL		INITIAL SET (min)			PLASTIC VOLUME CHANGE (%)			INITIAL FLOW - mm 75x150mm CYLINDER		
		+10°C	-5°C	-20°C	+10°C	-5°C	-20°C	+10	-5	-20°C
SET 45	6 CU IN	27	38	MATERIAL FROZE	0.1	0.2	0.2	255	150	90
	87 CU IN	22	35	80/1/						
	12x12x2.75"	-	-	80/2/						
	12x18x12"	-	-	70/2/						

NOTE:

/1/ SURFACE OF MATERIAL THAWED WHEN REMOVED FROM -20°C TO +23°C. MATERIAL HARDENED AS TEMPERATURE INCREASED.

/2/ MATERIAL HARDENED AT -20°C WITH NO SIGNS OF SOFTENING WHEN REMOVED TO 23°C (ENVIRONMENT).

TABLE 2

COMPRESSIVE STRENGTH OF SET 45

PLACING TEMP. (°C)	CURING TEMP. (°C)	TESTING TEMP. (°C)	COMPRESSIVE STRENGTH (psi)						
			2" CUBES			3"x6" CYLINDERS			
			AGE (DAYS)						
			1	7	28	4	7	39	52
10	10	10	5100	7730	8990	-	-	-	-
-5	-5	-5	3670	8610	9460	-	8080	- /1/	8020
-20	-20	-20	0	0	0	260	-	6690	-

/1/ MATERIAL CURED 10 DAYS AT -20°C + 20 DAYS AT 23°C.

NOTE: MATERIALS REMOVED FROM -5° AND -20°C ENVIRONMENTS AND TESTED IMMEDIATELY.

TABLE 3

PHYSICAL CHARACTERISTICS OF SET 45

MATERIAL	COEFFICIENT OF THERMAL EXPANSION X10E-6/°C	MODULUS OF RUPTURE (psi) AGE 28 DAYS 23°C	FREEZE-THAW RESISTANCE		HARDENED DENSITY kg/m³
			NUMBER OF CYCLES	DURABILITY FACTOR %	
SET 45	11.3	440	168	27.8	2210

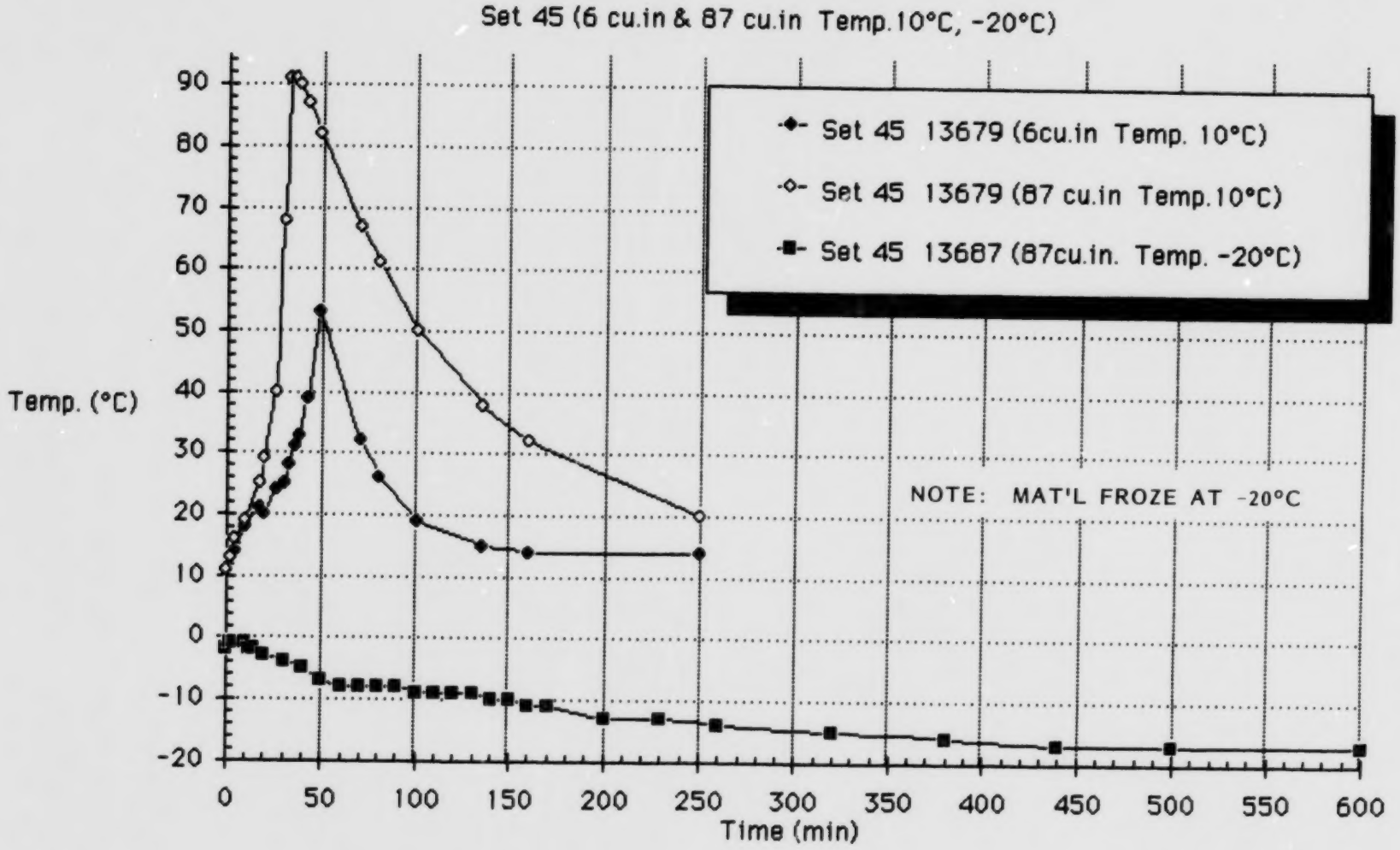

Set 45 (6 cu.in & 87 cu.in Temp.10°C, -20°C)
Set 45 13679 (6cu.in Temp. 10°C)
Set 45 13679 (87 cu.in Temp.10°C)
Set 45 13687 (87cu.in. Temp. -20°C)
NOTE: MAT'L FROZE AT -20°C
Temp. (°C)
90
80
70
60
50
40
30
20
10
0
-10
-20
0
50
100
150
200
250
300
350
400
450
500
550
600
Time (min)

FIGURE 1

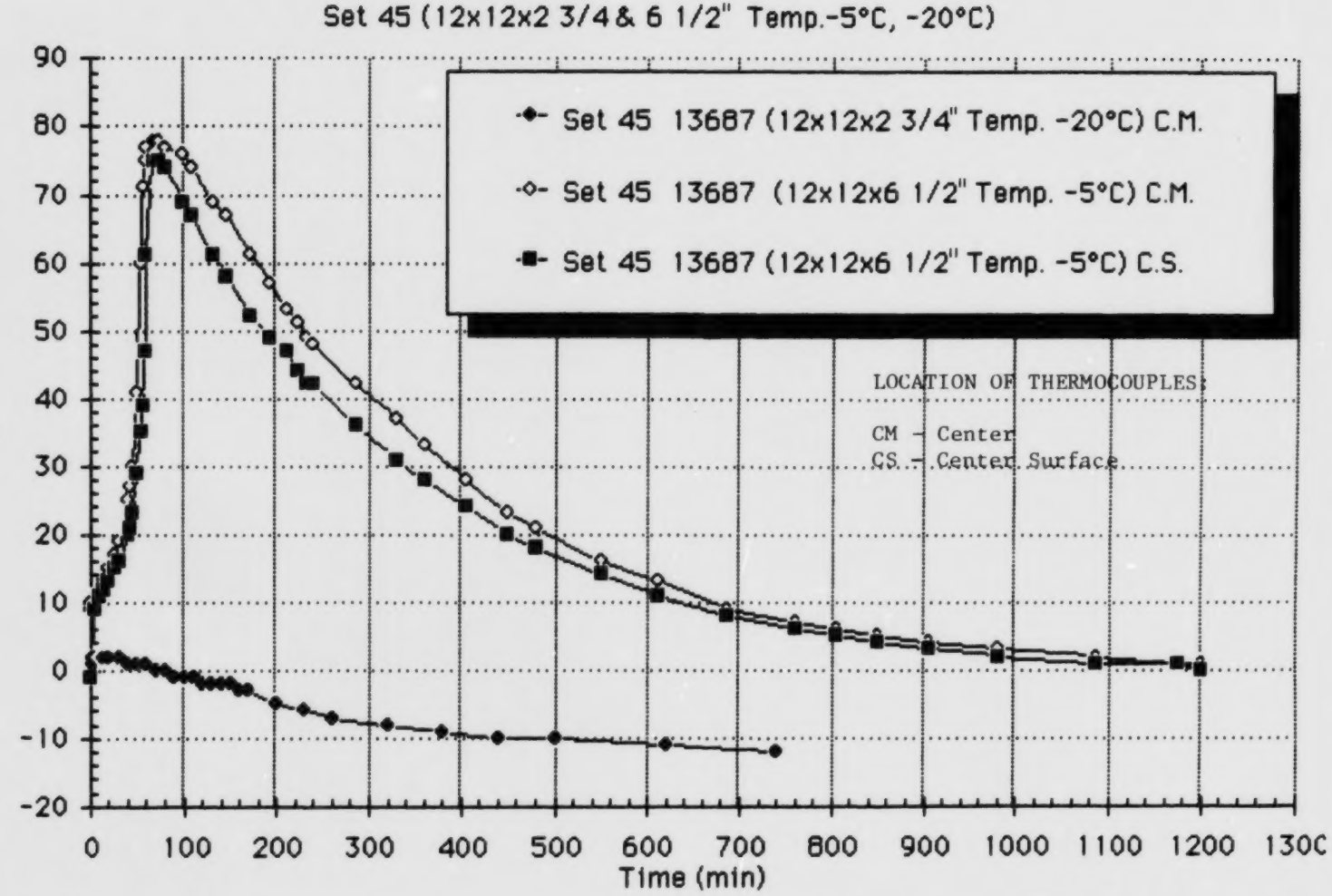

Set 45 (12x12x2 3/4 & 6 1/2" Temp.-5°C, -20°C)
Set 45 13687 (12x12x2 3/4" Temp. -20°C) C.M.
Set 45 13687 (12x12x6 1/2" Temp. -5°C) C.M.
Set 45 13687 (12x12x6 1/2" Temp. -5°C) C.S.
LOCATION OF THERMOCOUPLES:
CM - Center
CS - Center Surface
Temp. (°C)
90
80
70
60
50
40
30
20
10
0
-10
-20
0
100
200
300
400
500
600
700
800
900
1000
1100
1200
130C
Time (min)

FIGURE 2

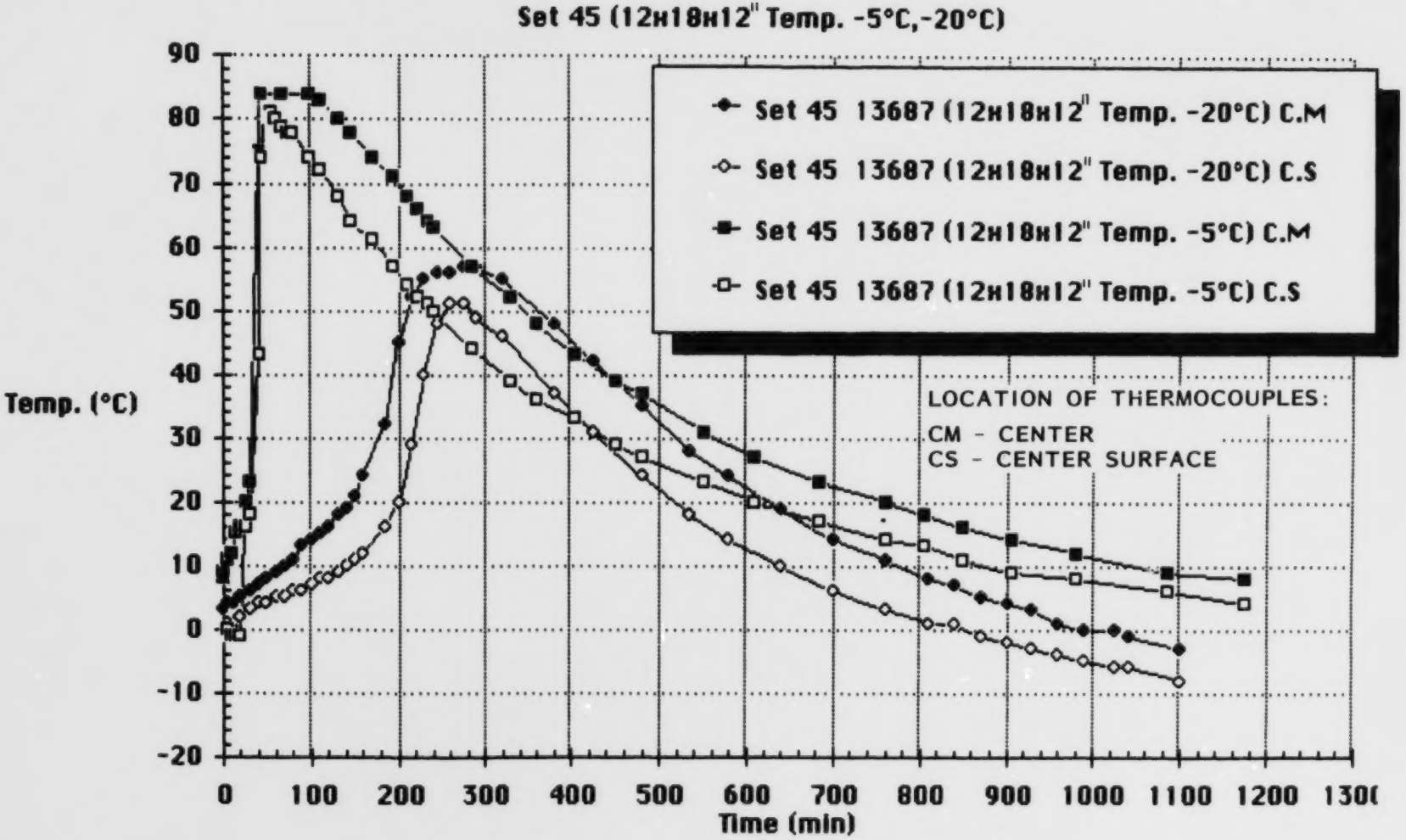


FIGURE 3

176162 RD
88-67

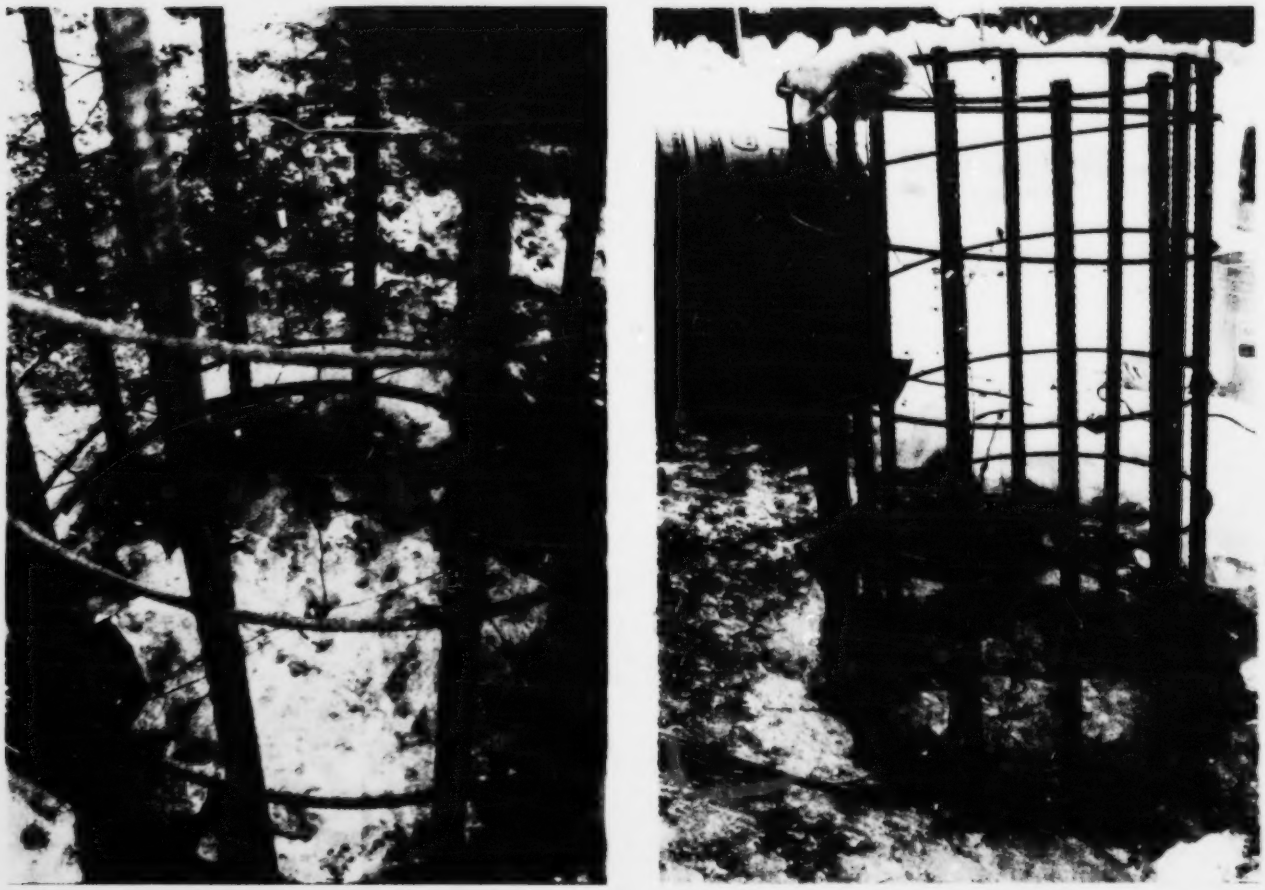


FIGURE 4

INSTALLATION OF THERMOCOUPLE WIRES

Thermocouple wires were installed at various elevations in the form to monitor temperature rise of Set 45 concrete

Rock surface was roughened then cleaned. Note roughness of rock surface for ensuring good mechanical bond of the Set 45 concrete.

176152 RD
GEM 1 DISK
88-67

FIGURE 5

PREPARATION OF FORMWORK FOR CASTING PIERS

After installing thermocouple wires and cleaning rock surface, sonotube formwork was installed.

176153 RD
GEM 1 DISK

FIGURE 5 (Cont'd)

Sonotube was positioned and braced using Set 45 grout at the base and 2"x4" wood to ensure proper concrete cover for the reinforcing steel.

176154 RD
GEM 1 DISK

88-67

Part of the mixing water added to the mixer first.

Set 45 grout then added, followed by addition of the 3/8" aggregate and remaining water.

FIGURE 6

MIXING OF SET 45 CONCRETE

176155 RD
GEM 1 DISK
88-67

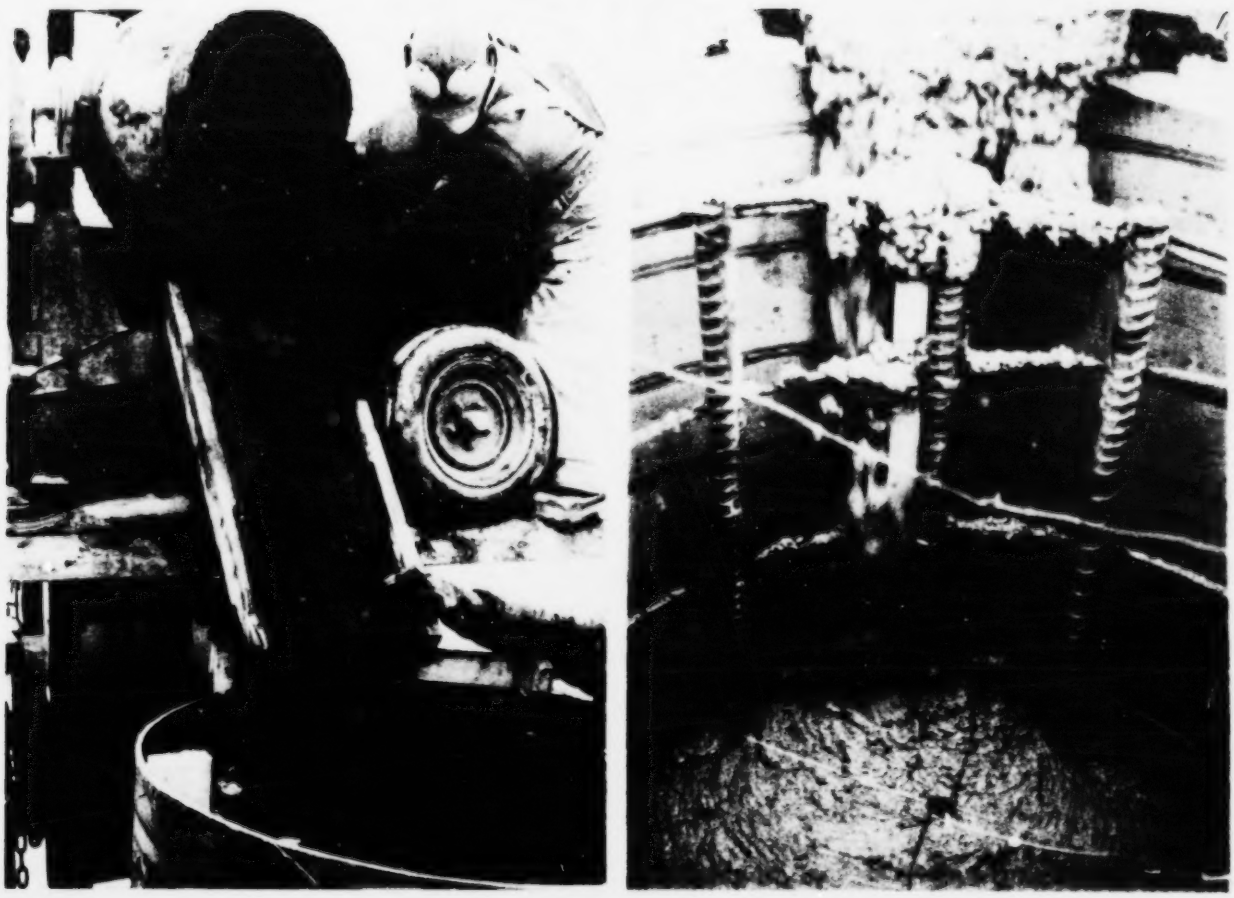


FIGURE 7

MIXING AND PLACING OF SET 45 CONCRETE

Set concrete when mixed at the manufacturer's recommended water to solids ratio produced a flowable concrete. The Set 45 concrete was discharged from the mixer onto a chute and into the form. No vibrators were used to consolidate the concrete.

APPENDIX A

TEST METHODS

Flowability	75 x 150 mm open ended cylinder used to measure horizontal spread.
Temperature Rise and Initial Set	The maximum temperature was determined using a thermocouple inserted into the center of the mass. The initial set was determined using a Proctor needle.
Plastic Volume	CAN3-A23.2-1B
Compressive Strength and Density	ASTM C 39; ASTM C 78
Modulus of Rupture	ASTM C 78
Thermal Coefficient of Expansion	ASTM C 531
Freeze-Thaw Resistance	ASTM C 666 Procedure A

176157 RD
GEM 1 DISK

APPENDIX B

TEST RESULTS

TABLE B2

Test Pad #2
Neat Set 45 Grout

Date	Location	Time	Ambient Temp (°C)	Material Temperature Prior to Mixing (C°)			Batch Number and Ingredients	Batch Size (kg)	Mixing Time (sec)	Material Temp After Mixing	Flow (mm)	Placing Time (sec)	Remarks
				Set 45	Aggregate (3/8" Nominal)	Water							
Dec 11/85	Elliott Lake	9:37	-4	-2	-	7	8 bags Set 45	181.5	5	+1	200	30	Water content varied between approximately 1.9 to 2.0 L per 22.7 kg bag of Set 45. The grout fluidity varied between 190 to 260 mm.
		9:44					8 bags Set 45		5		-	30	
		9:51		-1	-	8	8 bags Set 45		3	-	-	30	
		9:55		-	-		8 bags Set 45		6	+2	-	30	
		10:02		-1	-	11	8 bags Set 45		4	-	-	30	
		10:08		-	-	-	8 bags Set 45		4	+3	190	30	
		10:13		-	-	-	8 bags Set 45		3		-	30	
		10:18		-	-	-	8 bags Set 45		4	-	-	30	
		10:23		-	-	-	8 bags Set 45		4	-	-	30	
		10:28		-	-	-	8 bags Set 45		4	+4	260	30	
		10:33		-1	-	10	8 bags Set 45		4	-	-	30	
		10:38		-	-	-	8 bags Set 45		4	+4	-	30	
		10:44		-1	-	10	8 bags Set 45		4	+4	-	30	
		10:50		-1	-	10	8 bags Set 45		4		240	30	
							Total: 112 bags of Set 45						

Remarks: 1. A portion of the water added to the mixer first followed by the set 45 and then the remainder of the water.
2. Grout easily mixed producing a fluid consistency. Some bleeding and grout separation occurred on the surface of the grout after completion of placing. No difficulty in finishing surface of the grout.

(CV37)

TABLE B1

Test Pad #1
Set 45 + 3/8" Aggregate

Date	Location	Time	Ambient Temp (°C)	Material Temperature Prior to Mixing (C°)			Batch Number and Ingredients	Batch Size (kg)	Mixing Time (sec)	Material Temp After Mixing	Flow (mm)	Placing Time (sec)	Remarks
				Set 45	Aggregate (3/8" Nominal)	Water							
Dec 11/85	Elliott Lake	2:00 pm	-1	0	3	6	4 bags Set 45 2 bags aggregate	91 22.7	310	2	≈180	120	Water content varied between 1.9 and 2.1 litres per 22.7 kg bag during placement of Set 45. The grout flow varied between approx. 170 mm and 260 mm.
		2:08 pm	-1	-	-	-	6 bags Set 45 3 bags aggregate	136 34	300	-	-	34	
		2:15 pm	-1	-	-	-	6 bags Set 45 3 bags aggregate	136 34	265	-	-	30	
		2:20 pm	-1	-	-	-	6 bags Set 45 3 bags aggregate	136 34	245	-	-	30	
		2:26 pm	-1	-	-	-	6 bags Set 45 3 bags aggregate	136 34	263	2	170	33	
		2:32 pm	-1	-	-	-	6 bags Set 45 3 bags aggregate	136 34	300	-	-	20	
		2:39 pm	-1	0	1	6	6 bags Set 45 3 bags aggregate	136 34	273	-	-	17	
		2:47 pm	-1	-	-	-	6 bags Set 45 3 bags aggregate	136 34	240	-	-	23	
		2:53 pm	-1	-	-	-	6 bags Set 45 3 bags aggregate	136 34	245	-	≈245	24	
		2:58 pm	-1	0	2	6	6 bags Set 45 3 bags aggregate	136 34	301	2	-	21	
		3:04 pm	-1	-	-	-	6 bags Set 45 3 bags aggregate	136 34	300	-	-	24	
		3:11 pm	-1	-	-	-	6 bags Set 45 3 bags aggregate	136 34	250	-	260	24	
		3:17 pm	-1	0	2	6	6 bags Set 45 3 bags aggregate	136 34	300	-	-	22	
		3:24 pm	-1	-	-	-	6 bags Set 45 3 bags aggregate	136 34	240	2	-	20	
		3:28 pm	-1	-	-	-	6 bags Set 45 3 bags aggregate Total: Set 45 - 88 bags Agg. - 44 bags	136 34	255	-	-	25	

Remarks: From 2:00 pm to 2:53 pm water added to mixer first, followed by Set 45 and then aggregate.
From 2:58 pm to 3:28 pm water added to mixer first, followed by aggregate and then Set 45.
Grout easily mixed and placed. Minor bleeding occurred on surface of grout after completion of placing. No difficulty in finishing surface of grout. More water was required to produce a placeable grout consistency at the lower ambient temperatures.

(CV37)

TABLE B3

COMPRESSIVE STRENGTH
OF NEAT SET 45
12"x12"x18" LABORATORY BLOCKS

CORE SIZE (IN)	ORIGINAL CASTING TEMP. (°C)	MATERIAL TEMP. AT TIME OF PLACING (°C)	AGE AT TEST (DAYS)	ADDITIONAL CURING AT 100°C (DAYS)	COMPRESSIVE STRENGTH (psi)	PEAK TEMP(°C) MEASURED IN LABORATORY TEST BLOCK
4	-5	8	90*		6310	85
	-5		90**	1	2090	
4	-20	4-5	90*		6190	58
4	-20		90**	1	2090	
PAD 1 HOLE 1	FIELD CONDITIONS		47	1	695	
PAD 2 HOLE 4	FIELD CONDITIONS		47	1	1715	

* CURED 10 DAYS AT -5°C OR -20°C, THEN STORED AT 23°C UNTIL TESTED

** CURED 10 DAYS AT -5°C OR -20°C THEN 80 DAYS AT 23°C FOLLOWED BY 1 DAY AT 100°C THEN 24 HRS AT 23°C, THEN TESTED

TABLE B4

SET-45 MAGNESIUM PHOSPHATE CEMENT
X-RAY DIFFRACTION RESULTS

SAMPLE NO. (13276)	CURING CONDITIONS	AGE (DAYS)	MINERALOGICAL COMPOSITION (COUNTS/SECOND)				
			PERICLASE MgO	STRUVITE $NH_4 Mg PO_4 6H_2O$	DITTMARITE $NH_4 Mg PO_4 H_2O$	BRUCITE $Mg(OH)_2$	AMMONIUM PHOSPHATE $(NH_4)_3 H_2 P_3 O_{10}$
1	23°C-AIR	2	1200	115	770	6	24
2	23°C-WATER	1	>400	150	>400	10	38
3	50°C-AIR	1	>400	90	>400	6	24
4	100°C-AIR	1	>400	-*	>400	-	-
5 (PASTE)	50°C-AIR	2	1140	40	680	8	12
6 (PASTE)	100°C-AIR	2	1080	-*	660	-	-
7	23°C-AIR	7	1340	120	980	6	34
8	23°C-WATER	7	>400	170	400	-	40
9	23°C-AIR	28	>400	80	>400	8	26
10	23°C-WATER	28	1100	240	400	12	-

* STRUVITE IS NOT STABLE AT 100°C AND FORMS MORE EASILY IN WATER

NOTE: ALL PATTERNS EXHIBITED AN AMORPHOUS HALO BETWEEN 20-35°/2θ

TABLE B5

SET-45 MAGNESIUM PHOSPHATE CEMENT
X-RAY DIFFRACTION RESULTS

SAMPLE NO. (13276)	CURING CONDITIONS	AGE (DAYS)	MINERALOGICAL COMPOSITION				
			PERICLASE MgO	STRUVITE NH_4 Mg PO_4 $6H_2O$	DITTMARITE NH_4 Mg PO_4 H_2O	BRUCITE $Mg(OH)_2$	AMMONIUM PHOSPHATE $(NH_4)_3$ H_2 P_3 O_{10}
1	23°C-AIR	2	MAJOR	MINOR	MAJOR	TRACE	TRACE
2	23°C-WATER	1	MAJOR	MINOR+	MAJOR	TRACE	TRACE
3	50°C-AIR	1	MAJOR	MINOR	MAJOR	TRACE	TRACE
4	100°C-AIR	1	MAJOR	-*	MAJOR	-	-
5 (PASTE)	50°C-AIR	2	MAJOR	MINOR	MAJOR	TRACE	TRACE
6 (PASTE)	100°C-AIR	2	MAJOR	-*	MAJOR	-	-
7	23°C-AIR	7	MAJOR	MINOR	MAJOR	TRACE	TRACE
8	23°C-WATER	7	MAJOR	MINOR+	MAJOR	-	TRACE
9	23°C-AIR	28	MAJOR	MINOR	MAJOR	TRACE	TRACE
10	23°C-WATER	28	MAJOR	MINOR+	MAJOR	TRACE	-

* STRUVITE IS NOT STABLE AT 100°C AND FORMS MORE EASILY IN WATER

NOTE: ALL PATTERNS EXHIBITED AN AMORPHOUS HALO BETWEEN 20-35°/2θ

176150 RD
88-67

TABLE B6

FREEZE/THAW TESTS FOR SET 45
A.S.T.M. C 666
PROCEDURE A

SPECIMEN	3/8" SILICA AGGREGATE	SET 45 GROUT (kgs)	WATER (L)	CURING ENVIRONMENT FOR 14 DAYS	NUMBER OF FREEZE/THAW CYCLES	WEIGHT CHANGE (%)	DURABILITY FACTOR
1	-	22.7	1.9	23°C AIR/1/	42	+0.22	6.4
					54	-0.37	9.6
2	11.34	22.7	1.9	23°C AIR/1/	42	+0.07	7.4
					42	-0.07	7.2
3	11.34	22.7	1.9	23°C AIR/2/	42	-0.14	8.0
					42	-0.14	5.8
					42	0	4.6
4	11.34	22.7	2.28	23°C AIR/2/	42	-0.14	5.6
					42	-0.14	6.2
					42	-0.21	6.6

/1/ SPECIMENS AFTER CASTING RESTRAINED FOR FIRST 24 HOURS
/2/ SPECIMENS AFTER CASTING UNRESTRAINED FOR FIRST 24 HOURS

176151 RD
88-67

QUANTITY OF GROUT PLACED WITH TIME
PAD 1 & 2
AMOUNT OF MIXED GROUT PLACED (BAGS)
0
30
60
90
120
150
TIME (MINUTES)
0
25
50
75
100
125
PAD 2
PAD 1

FIGURE B1

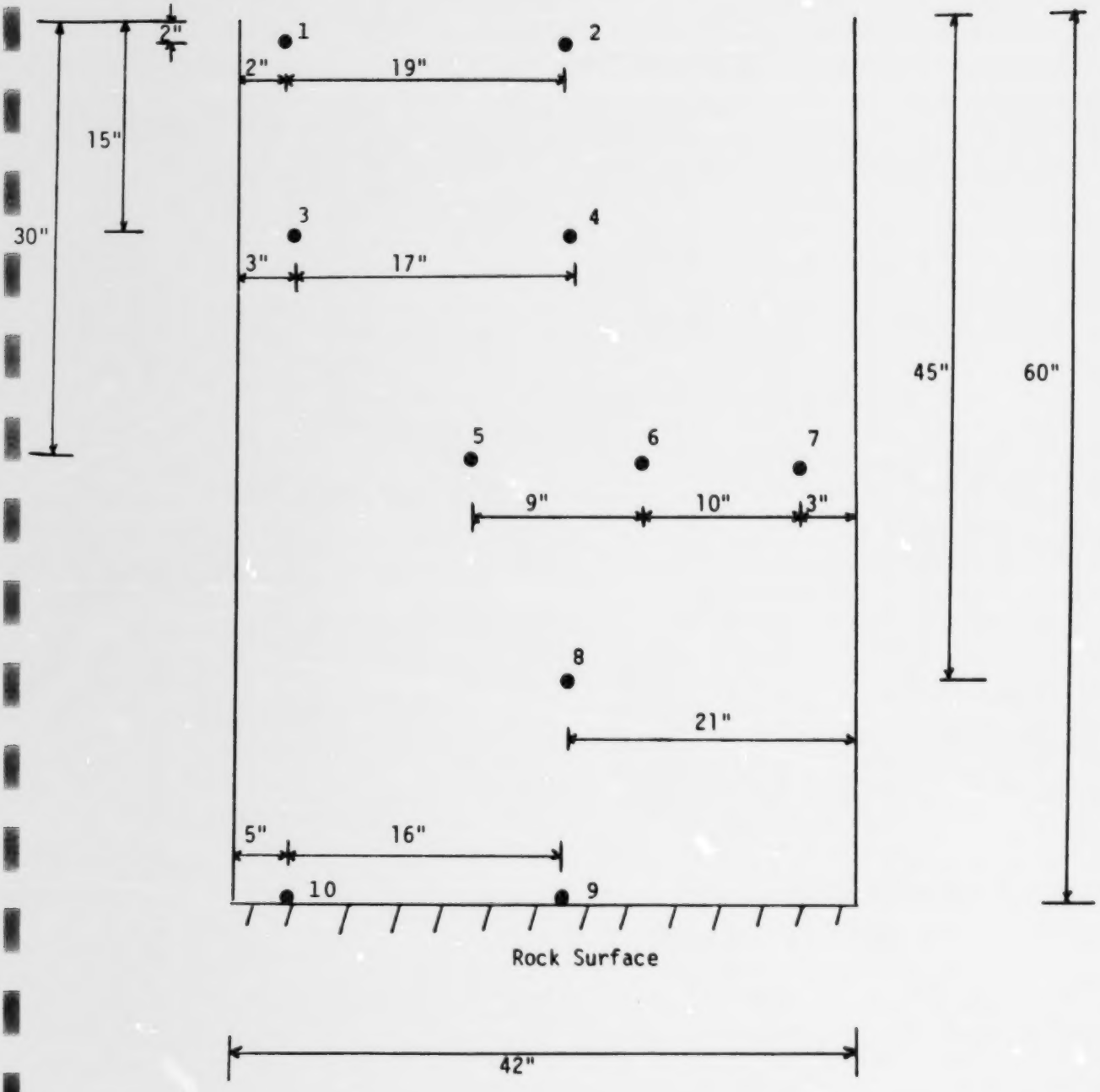


FIGURE B2

TEST PAD #1
APPROXIMATE LOCATION OF THERMOCOUPLE WIRES

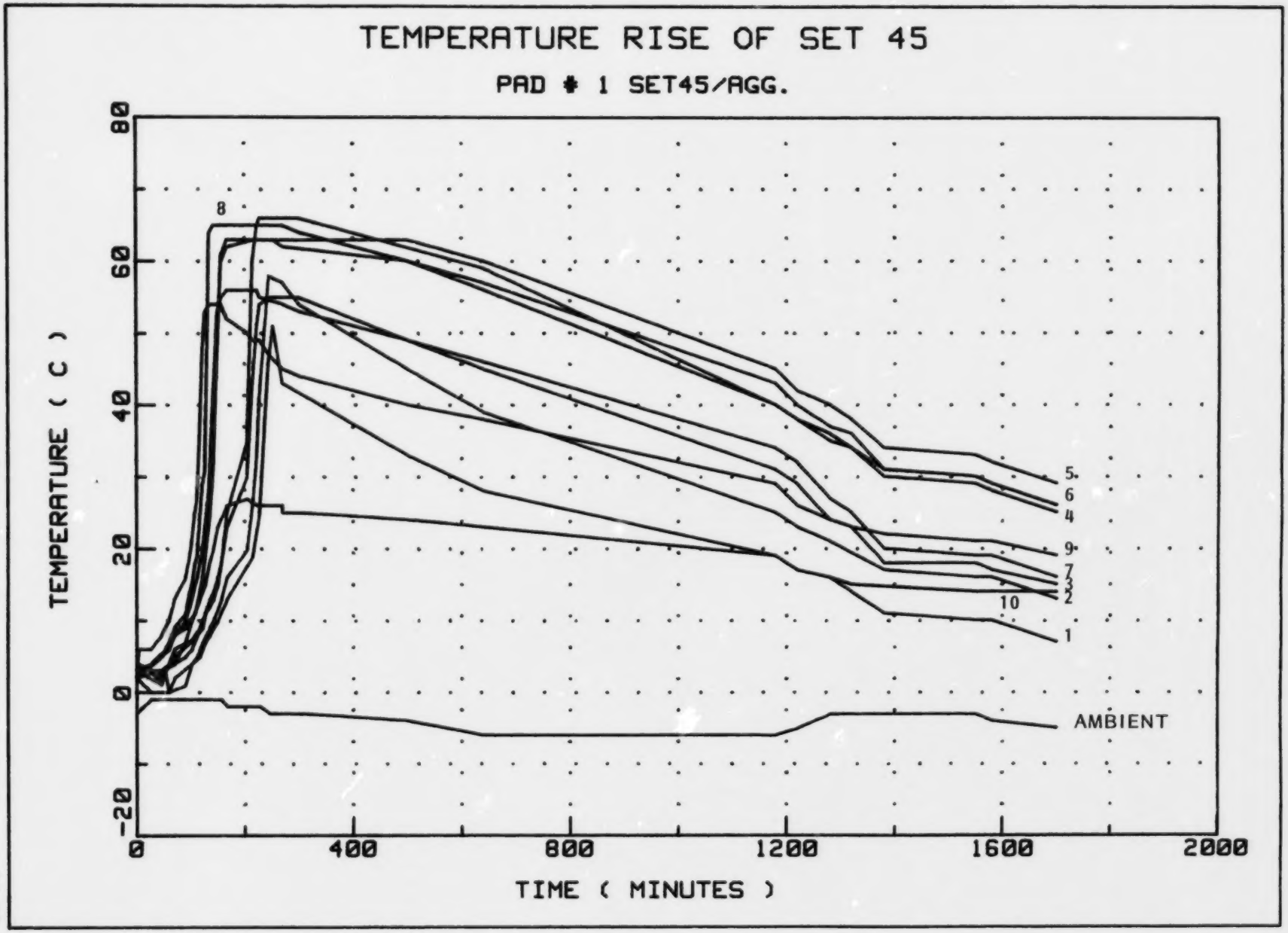

TEMPERATURE RISE OF SET 45
PAD # 1 SET45/AGG.
TEMPERATURE (C)
80
60
40
20
0
-20
0
400
800
1200
1600
2000
TIME (MINUTES)
8
5
6
4
9
7
3
2
10
1
AMBIENT

FIGURE B3

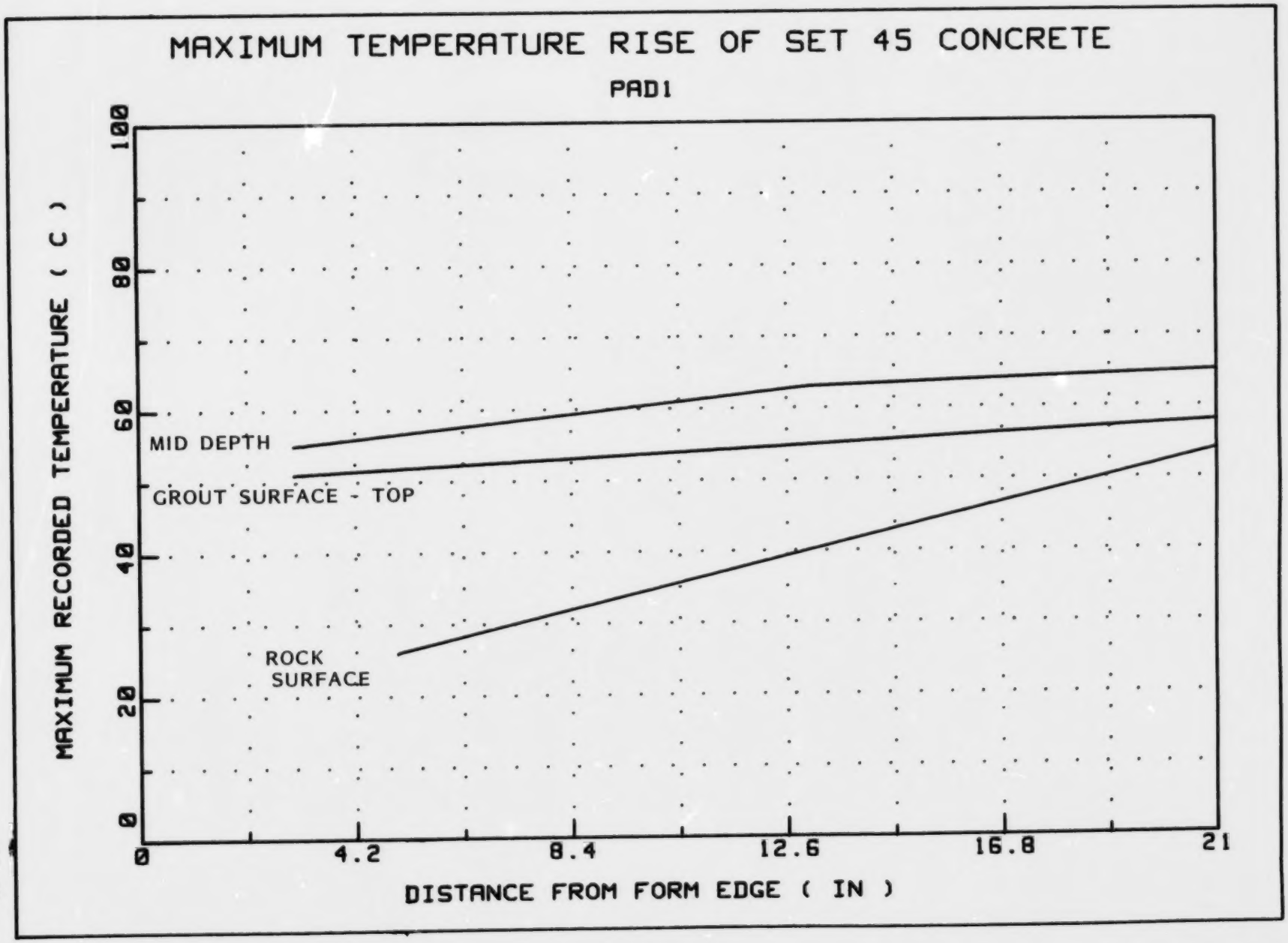

MAXIMUM TEMPERATURE RISE OF SET 45 CONCRETE
PAD1
MAXIMUM RECORDED TEMPERATURE (C)
100
80
60
40
20
0
MID DEPTH
GROUT SURFACE - TOP
ROCK
SURFACE
0
4.2
8.4
12.6
16.8
21
DISTANCE FROM FORM EDGE (IN)

FIGURE B4

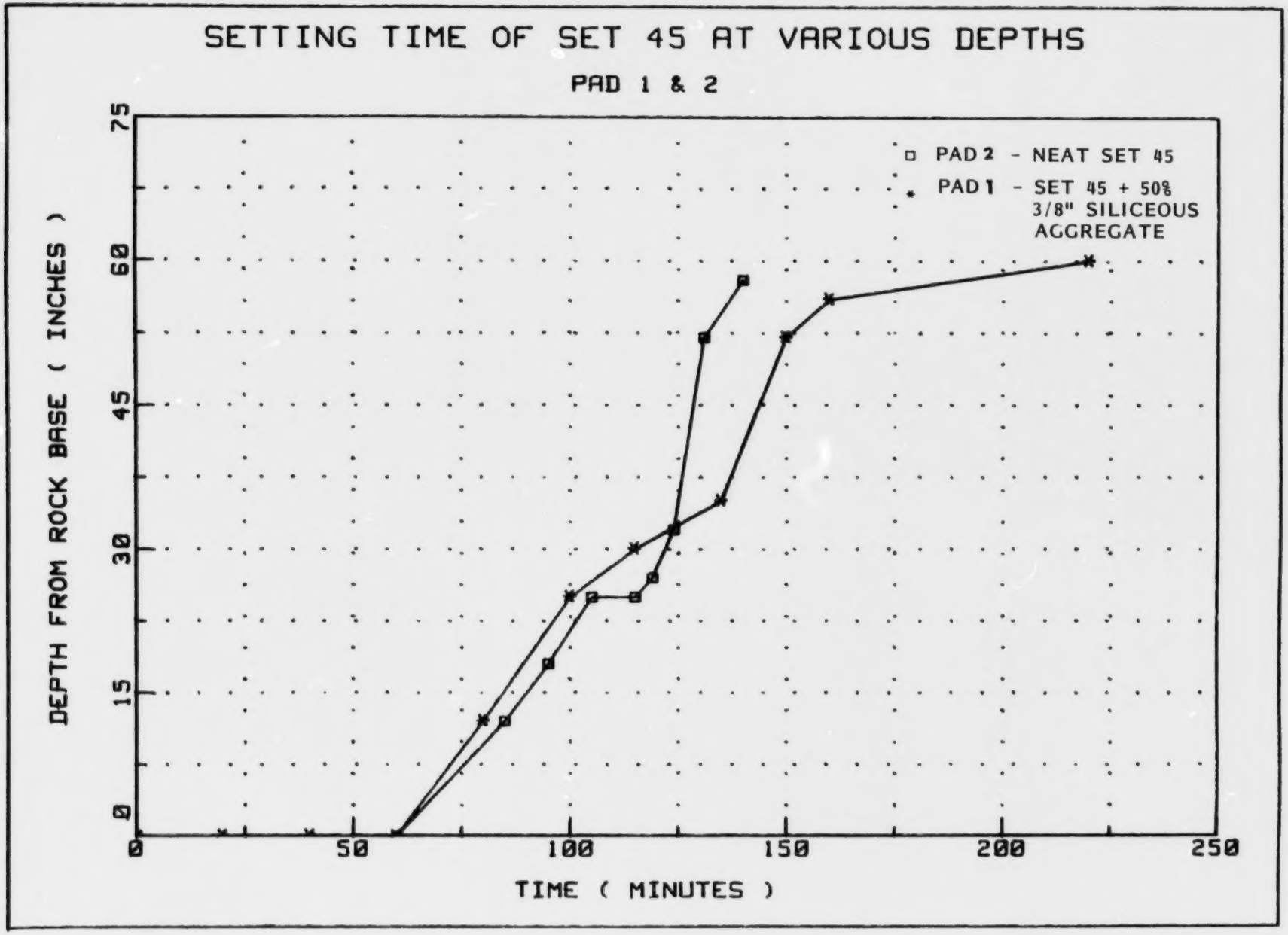

SETTING TIME OF SET 45 AT VARIOUS DEPTHS
PAD 1 & 2
PAD 2 - NEAT SET 45
PAD 1 - SET 45 + 50% 3/8" SILICEOUS AGGREGATE
DEPTH FROM ROCK BASE (INCHES)
0
15
30
45
60
75
0
50
100
150
200
250
TIME (MINUTES)

FIGURE B5

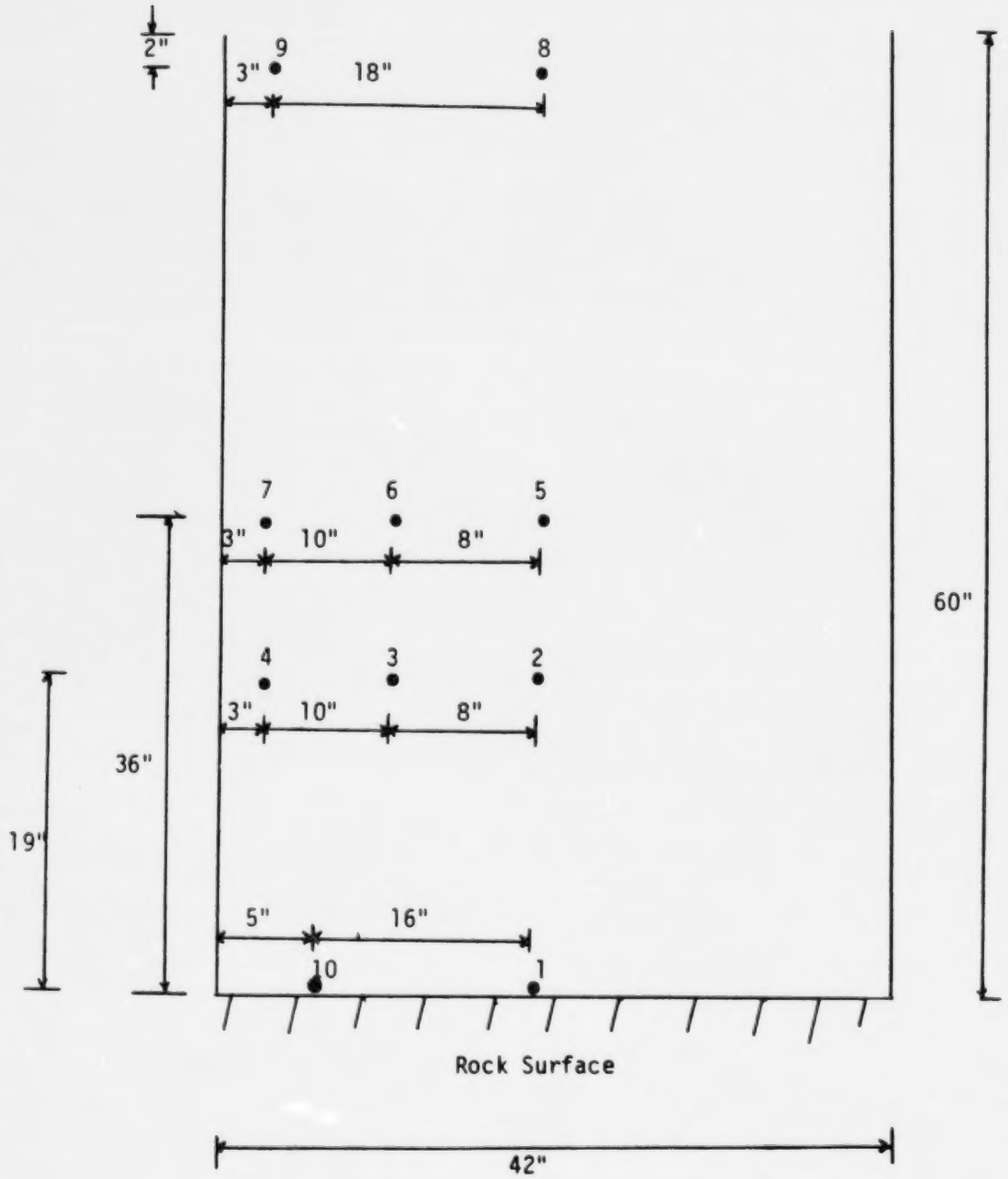


FIGURE B6

TEST PAD #2
APPROXIMATE LOCATION OF THERMOCOUPLE WIRES

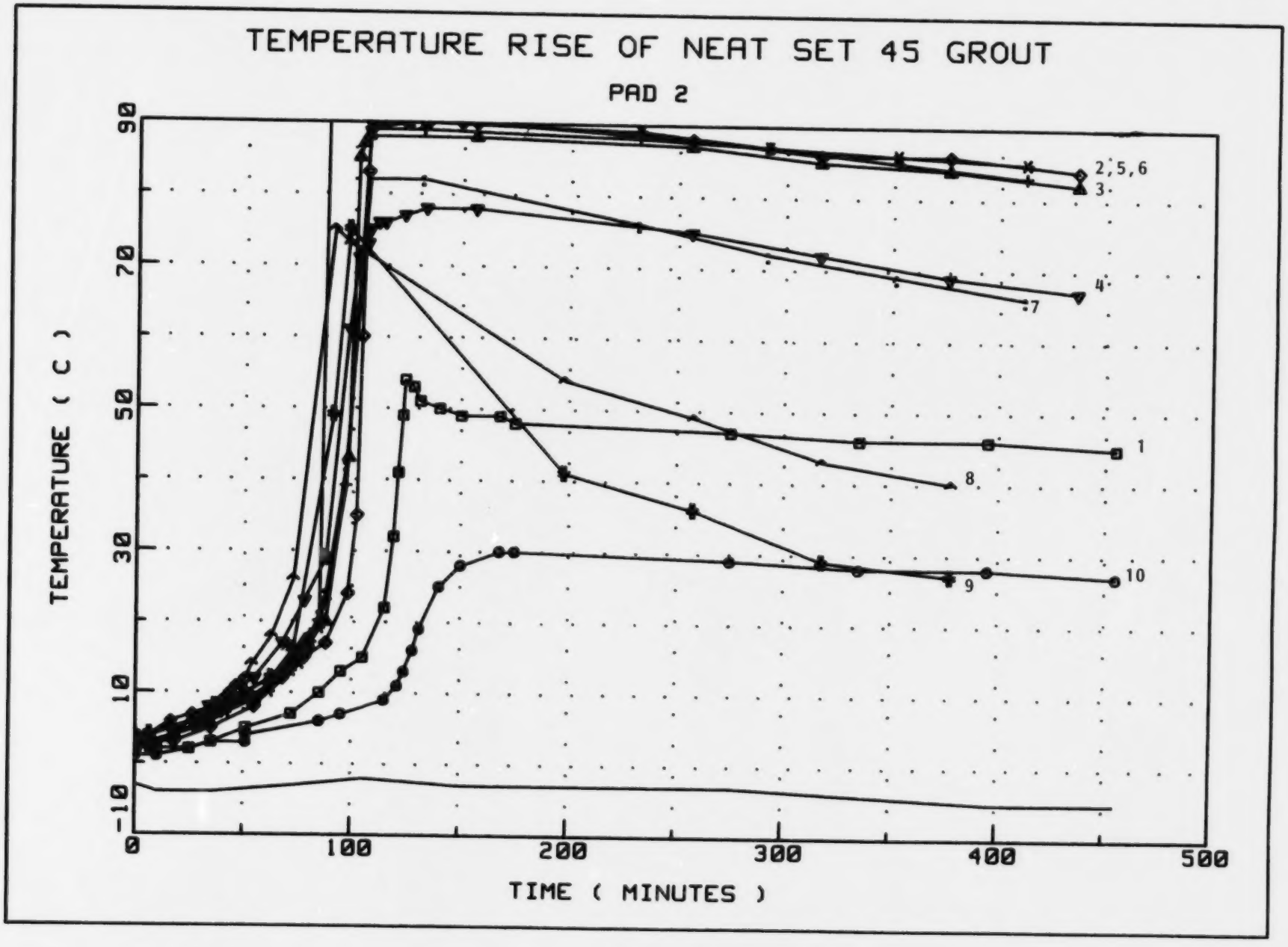


FIGURE B7

88-67
176139 RD

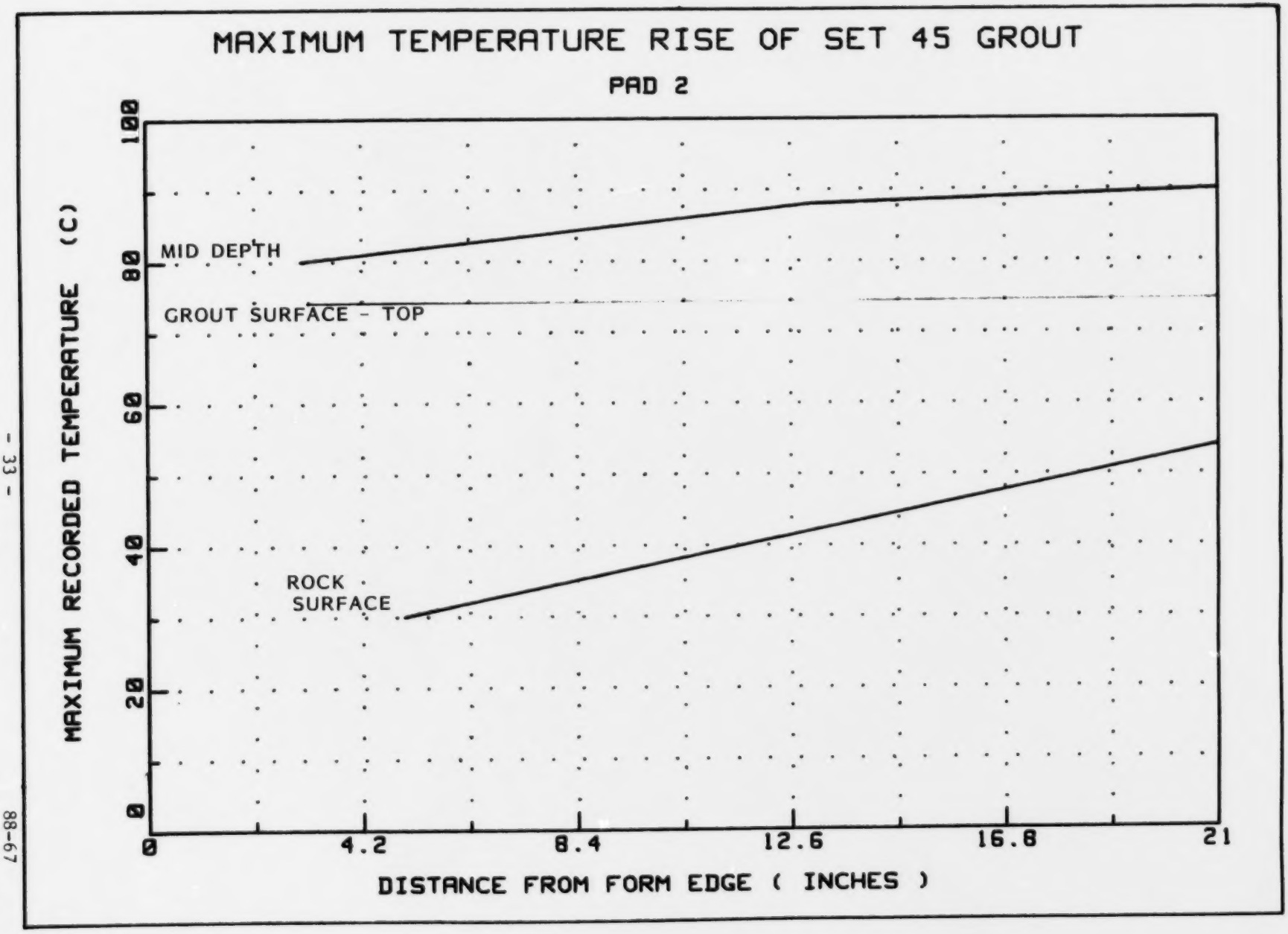


FIGURE B8

88-67
176140 RD

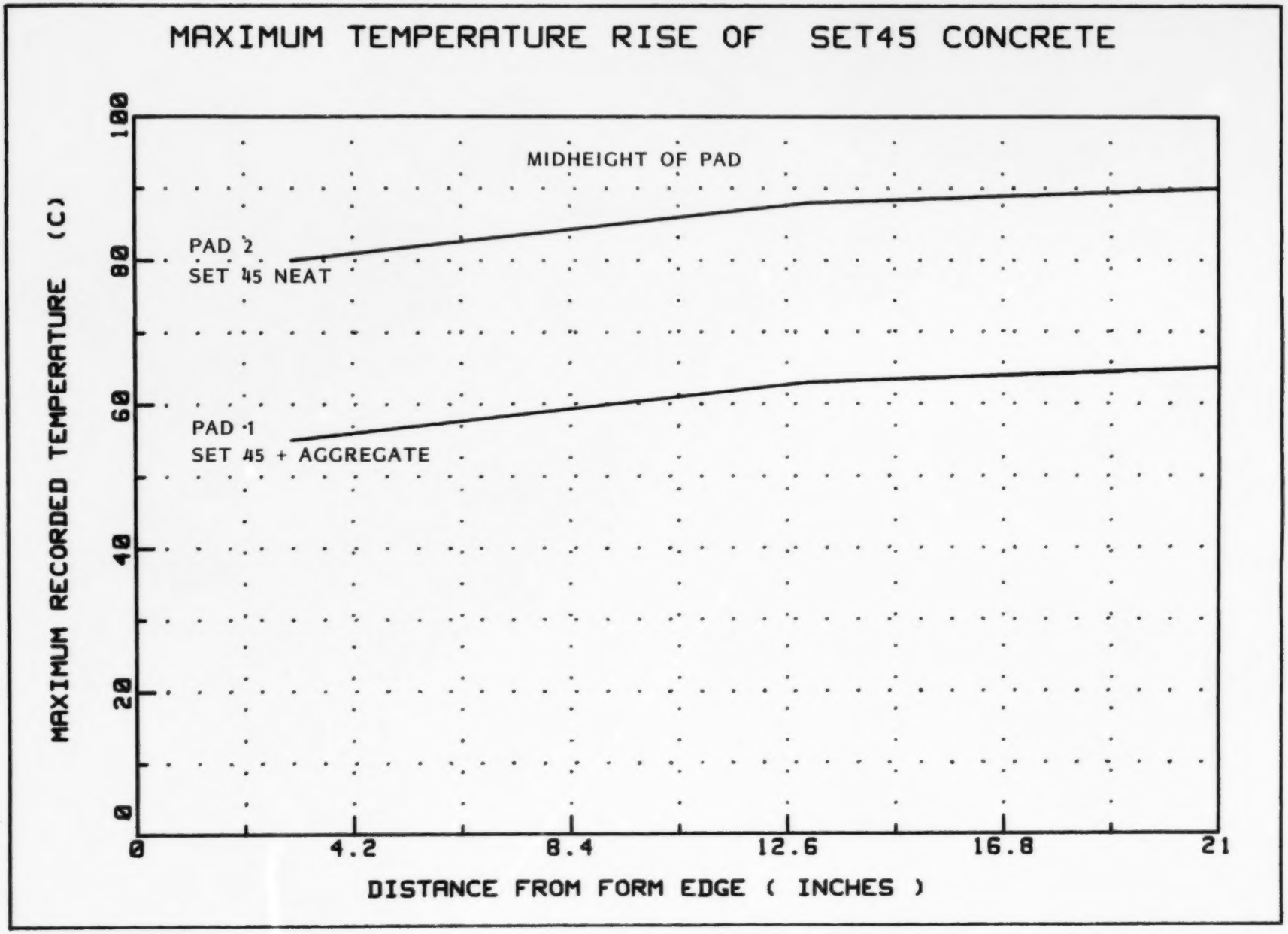


FIGURE B9

176141 RD
88-67

FIGURE B10

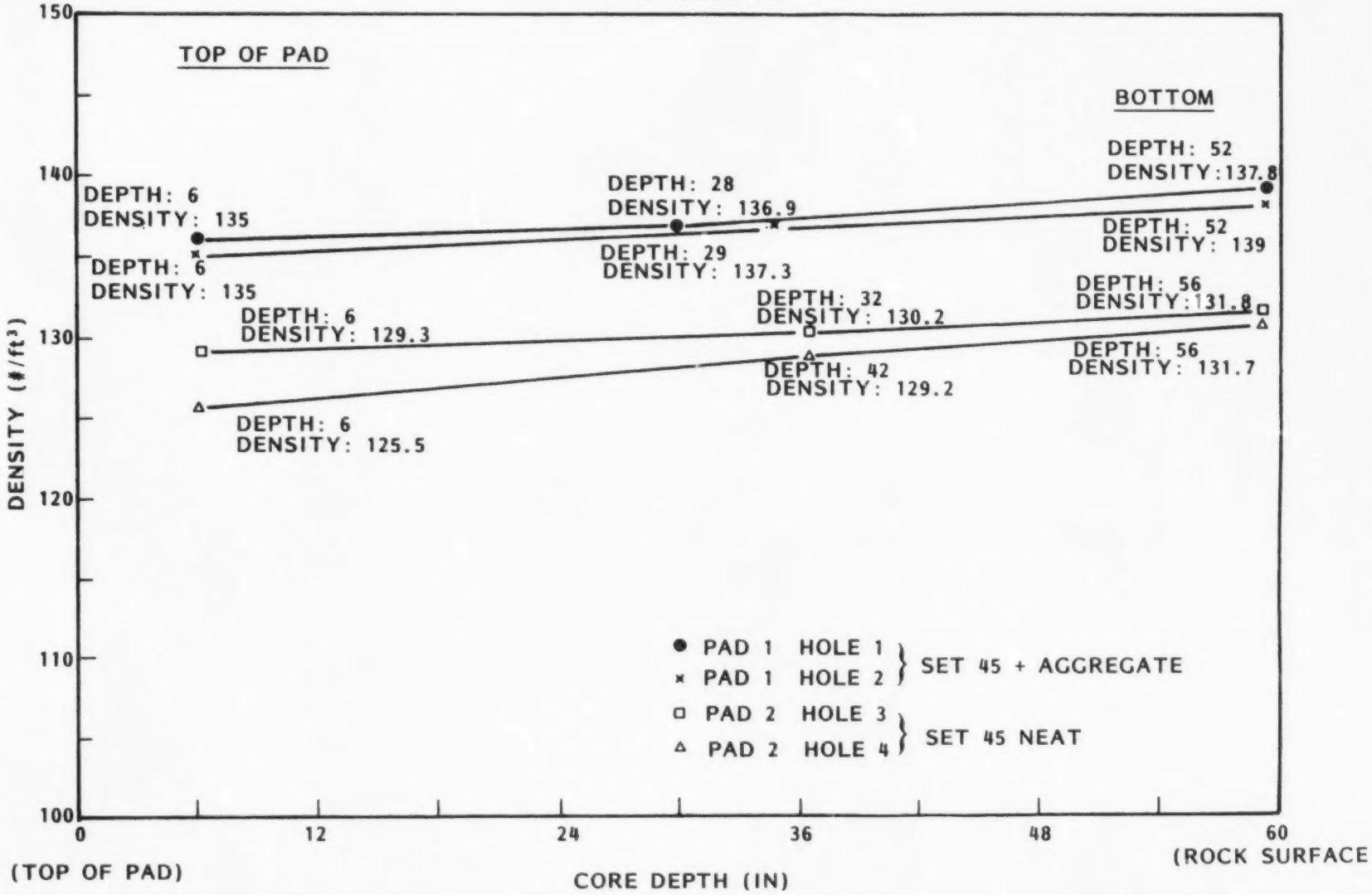
VIEW OF HARDENED SET 45 - PAD 2

Sonotube stripped approximately 24 hours after placing. Note steam coming off concrete. Material temperature approximately 42°C.

FIGURE B11

FIELD TRIALS SET 45 PADS

TEST RESULTS

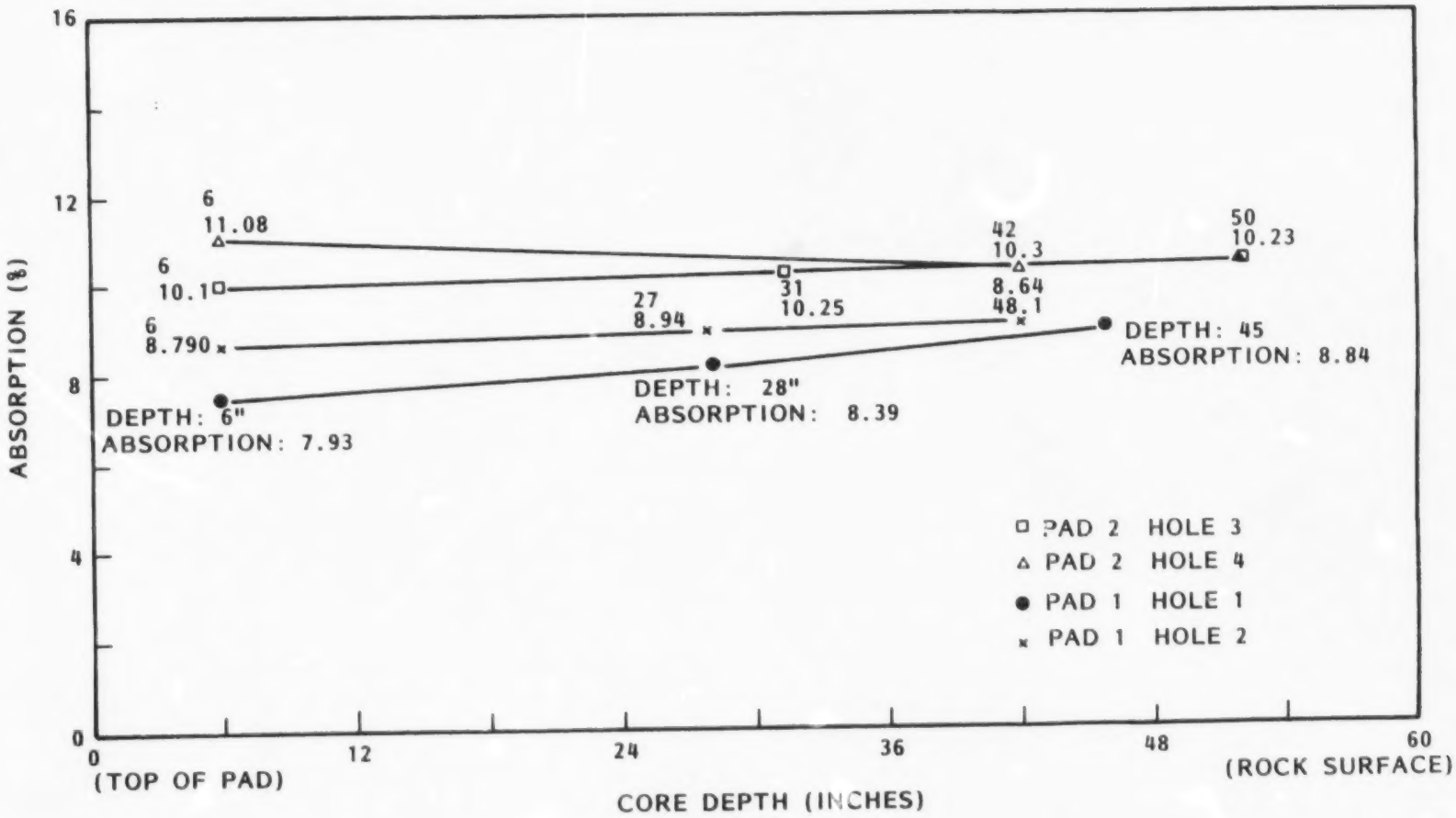


88-67
176143 RD

FIGURE B12

FIELD TRIALS SET 45 PADS

TEST RESULTS



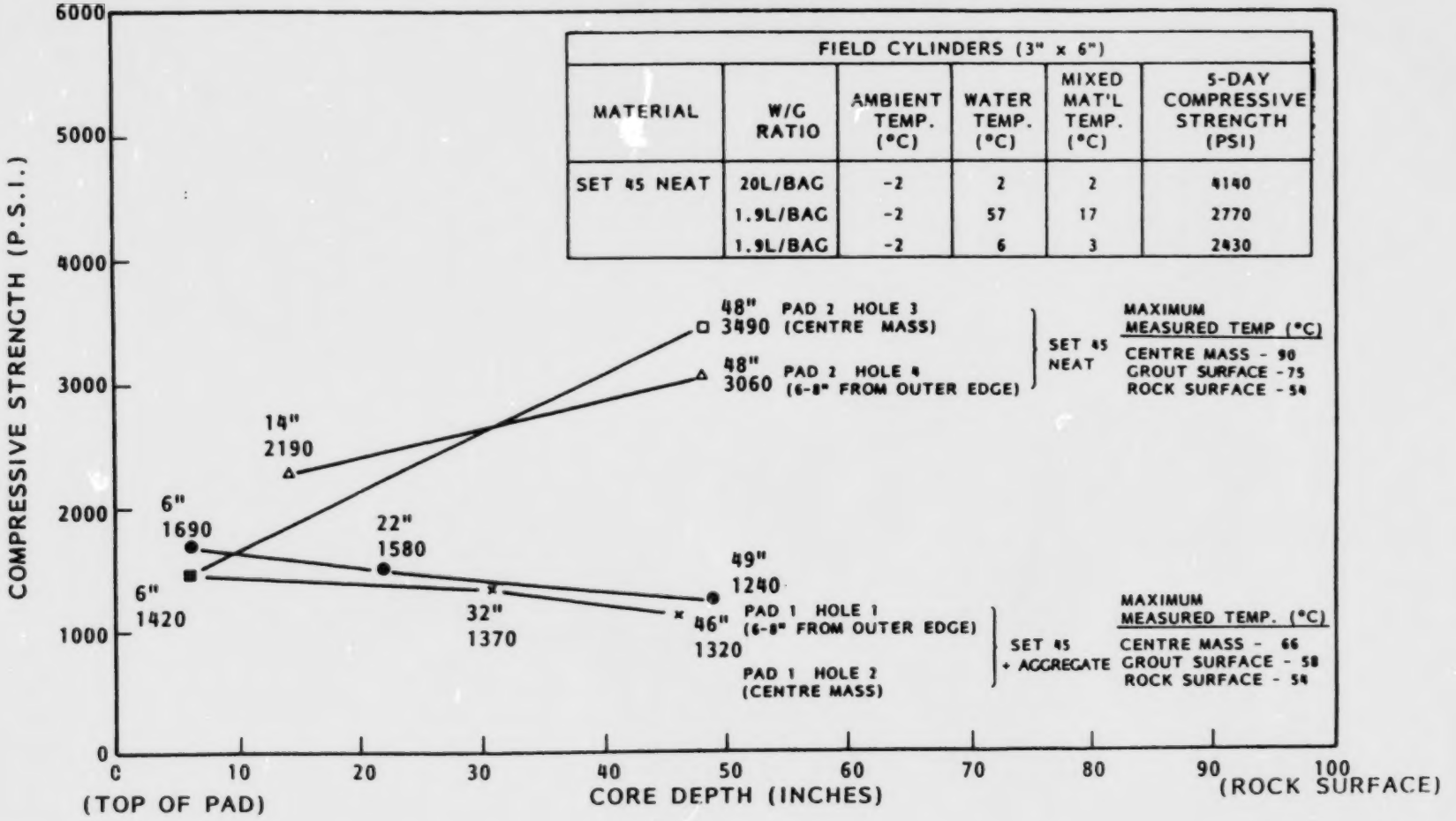
98-67
176144 RD

FIGURE B13

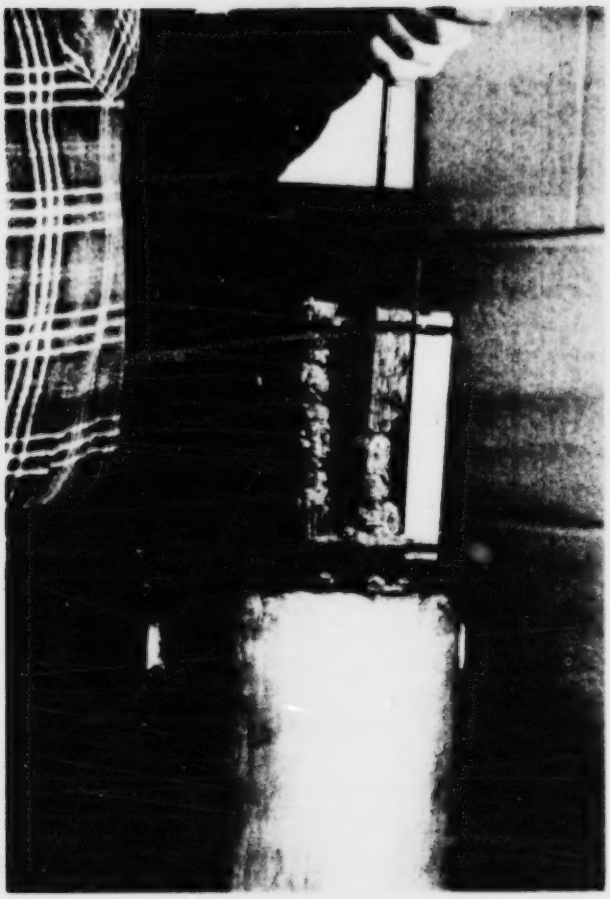
FIELD TRIALS SET 45 PADS

TEST RESULTS

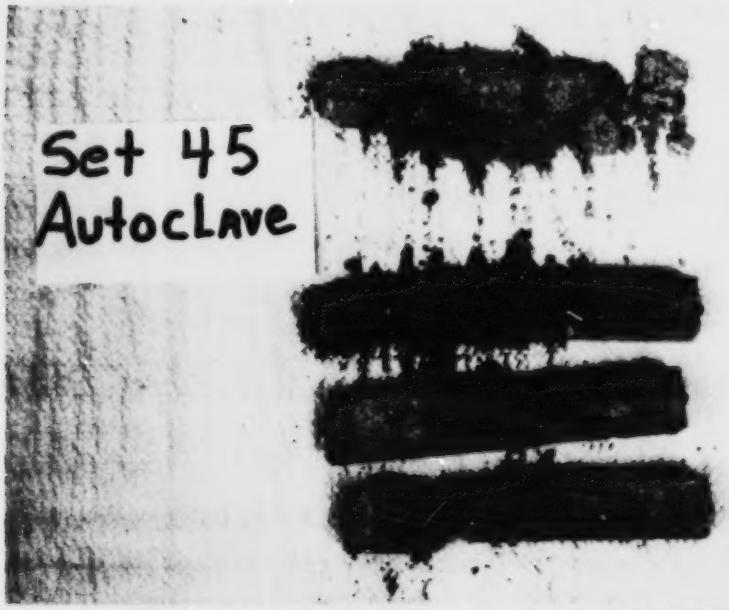
AGE: 47 DAYS FROM TIME OF PLACING PAD



FIELD CYLINDERS (3" x 6")					
MATERIAL	W/C RATIO	AMBIENT TEMP. (°C)	WATER TEMP. (°C)	MIXED MAT'L TEMP. (°C)	5-DAY COMPRESSIVE STRENGTH (PSI)
SET 45 NEAT	20L/BAG	-2	2	2	4140
	1.9L/BAG	-2	57	17	2770
	1.9L/BAG	-2	6	3	2430



Compressive Strength (MPa) - 1.9 L/Bag, 19.6 MPa
2.28 L/Bag, 16.5 MPa



Set 45 mixed at a W/G ratio of 1.9 and 2.28 l/Bag

FIGURE B14

AUTOCLAVE EXPANSION

176146 RD
GEM 1 DISK

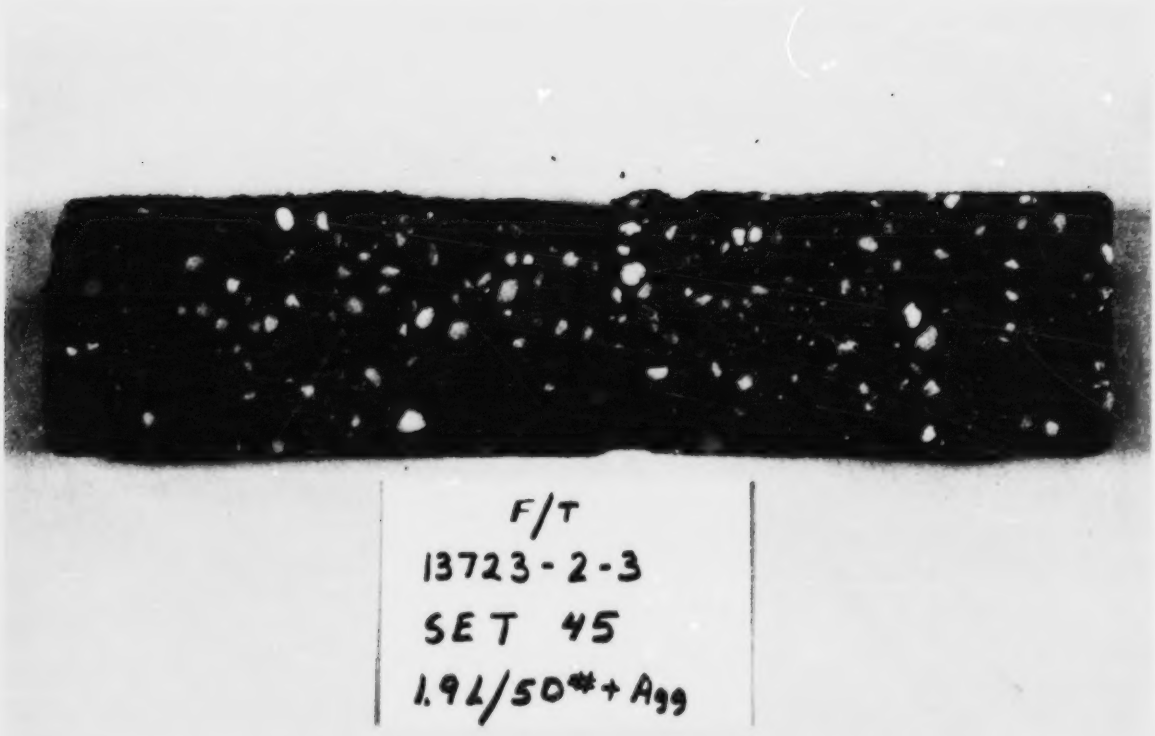


FIGURE B15

FREEZE-THAW ASTM C 666 PROCEDURE A

APPENDIX C

MANUFACTURER'S TEST RESULTS

August 17, 1987

Mr. John Deans
Ontario Hydro
800 Kipling Avenue
Toronto, Ontario M8Z 5S4
Canada

Dear John:

SUBJECT: MASTER BUILDERS/ONTARIO HYDRO MEETING

The following is a summary of our joint meeting in Cleveland from the Master Builders participation:

1. R. R. Nicholson. Presented lab data on the durability testing of Set-45 per ASTM C 666 with Holmes Independent Lab data and more recent '86 Solar Lab Reports indicating 100% @ 300 cycles.

   The information from '83 showed that 96% durability factor when tested at 70°F and only 57% when tested @ 90°F, indicating sensitivity of testing of specimen using same Hot Weather Set-45.

   Confirmation of low durability factors reported by Ontario Hydro using Set-45 submitted from the job when tested with aggregates supplied.

   Presented recently developed data on compressive strength of 2" cubes vs. larger specimen. Confirmed findings at Ontario Hydro that mass has effect on strength level attained.

2. Charles Nmai. Presented data on heat development indicating absolute need of aggregate extension with Regular Set-45 in more massive placements from recent research.

   Size effect study confirmed magnitude of temperature rise and retention level of large insulated specimens of Regular repair Set-45 to be close to that observed by Onatario Hydro.

   Also, presented data on flexural strength vs. specimen size from recent research on Set-45 which confirmed size effect behavior similar to portland cement concrete.

4. Frank Gay. Discussed formation of Struvite and Dittmarite. The X-ray data patterns from job submitted materials tested at Master Builders indicated no Brucite formed in autoclave specimens with or without aggregates, confirming acceptable autoclave results.

   Petrographic and x-ray information indicated poor quality of silica aggregate used in field and lab testing at Ontario Hydro. Samples of RM-215 Pea Gravel from Master Builders Lab stock supplied for comparison purposes.

continued . . . . .

23700 CHAGRIN BOULEVARD
CLEVELAND, OHIO 44122
PHONE 216/831-5500
TELEX 980-305

5. R. Gulyas. Presentation on typical repair applications of Set-45 for bridge, pavement and overlay work.

   Presentation on other engineering properties of Set-45 including setting time, bond strength, chloride ion uptake, volume change characteristics, and other features not typically associated with Regular and Hot Weather Set-45.

6. J. Truax. Presentation on quality control program of Set-45 including purchased materials control, and physical and chemical testing of production by Master Builders.

7. Inspection of research and technical facilities. Noted allowable differences are freeze thaw testing frequency.

   Specimen size differences in autoclave units both cross sectional area and length of bars used.

8. R. R. Nicholson. Review of evolution of Set-45 product at Master Builders. Major changes in Q/C program and control noted.

9. Summary of Findings. Unresolved freeze thaw testing and autoclave testing discrepencies. Program outlined to pinpoint differences.

Master Builders is prepared to run further testing to verify:

1. Freeze/thaw resistance differences of all formulations of Set-45 including a newly developed intermediate material which has specific application for Cold Weather more massive applications to lower peak heat without freezing prior to early hydration heat evolution.

2. Autoclave testing differences with different samples of Set-45 using different silica pea gravel.

3. Evaluate time/temperature effect of different formulations, including newly developed intermediate material.

We hope this adequately summarizes the basic findings of the joint meeting.

Sincerely,

R Gulyas

Robert J. Gulyas
Marketing Manager
Construction Products Marketing

RJG:hg

Report No. 86-102 MC
April 3, 1986

SUBJECT: SET-45, LOT NO. X3159Y5
PEA GRAVEL AGGREGATE
FROM JOBSITE
ONTARIO HYDRO

This report covers the results of physical tests and microscopical examination of samples of materials received from a jobsite in which the customer, Ontario Hydro, has reported very low compressive strengths. The submitted materials included seven bags of Set-45 (three were received opened) and two, 50 lb. bags of 3/8" pea gravel.

Construction Products Marketing requested quality control compliance tests on Set-45. Additional tests included autoclave expansion, unit weight, and compressive strength. X-ray powder diffraction analyses of before and after autoclaved samples and microscopic examination of Set-45 and pea gravel were also requested.

PHYSICAL TESTS

Tests were conducted on Set-45 and Set-45 extended with 25 lbs. of pea gravel for every 50 lbs. of Set-45.

A specified (as per bag instructions) mixing water of 4.2 lbs. per 50 lbs. of product was employed in these tests.

AUTOCLAVE EXPANSION, %
ASTM C 151 MODIFIED

Bar	Neat	Pea Gravel
A	+.015	+.028
B	+.012	+.028
Average	+.014	+.028

Continued . . . 88-67

UNIT WEIGHT
4" CUBE, LBS./FT.^{3}

	Neat	Pea Gravel
Fresh	137.7	143.1
Hardened (28 Days)	132.3	142.3

COMPRESSIVE STRENGTH
AVG. PSI (MPa)

Age	Neat 2" Cubes	Pea Gravel 3" x 6" Cylinders
1 Hour	3450 (23.8)	1863 (12.8)
1 Day	6450 (44.4)	2784 (19.2)
7 Day	6220 (42.9)	3130 (21.6)
28 Day	9025 (62.2)	3852 (26.6)

This particular batch of Set-45 (X3159Y5) was found to conform to or exceed the requirement of the quality control specifications.

PETROGRAPHIC
SAMPLE PREPARATION AND METHODS

The sample of pea gravel was examined microscopically.

A portion of the sample of unused Set-45 was sieved through a U.S. Standard No. 170 sieve and the material passing the sieve and retained in the pan was presumed to be composed of the cementitious components of the product.

Portions of the nonautoclaved samples and the autoclaved mortar bars were ground in a mortar and pestle and passed through a U.S. Standard No. 170 sieve. The material passing the sieve was presumed to be primarily composed of the paste of the samples. The powders representative of the respective samples were then examined by means of x-ray powder diffractometry.

Continued 88-67 . . .

Floor and Grout

MAR 26 1986

Marketing

Report No. 86-8 MC
March 25, 1986

SUBJECT: SET-45 REGULAR
LOT NO. X323525
ONTARIO HYDRO
ONTARIO, CANADA

The Construction Products Marketing Department submitted a request to test the subject sample for durability at various water contents and autoclave expansion. It was suggested that these tests be conducted on the submitted neat material with the addition of 3/8" pea gravel at the rate of 25 lbs. to 50 lbs. of Set-45.

Autoclave tests were conducted on specimens that were 24 hours old and others at 14 days old.

Additional tests were conducted by the Petrographic Laboratory to determine x-ray diffraction analysis of specimens prepared from the submitted sample. Microscopical examinations were conducted on freeze-thaw specimens upon completion of testing.

AUTOCLAVE
ASTM C 151, MODIFIED
AGE, 24 HOURS

	Moist Cured	Air Cured
Neat	+.025%	+.018%
Pea gravel	+.072%	+.095%

AGE, 14 DAYS

Neat	+.013%	+.025%
Pea gravel	+.021%	+.036%

RAPID FREEZE-THAW
ASTM C 666-84
NEAT MATERIAL

Mix Water	Specimen	Cycles	D/F
Increased by 20%	A	66	60
	B	136	56
		Avg.	58
Normal	A	66	46
	B	66	46
		Avg.	46
Reduced by 20%	A	36	41
	B	66	45
		Avg.	43

PEA GRAVEL ADDED

Increased by 20%	A	66	50
	B	66	53
		Avg.	52
Normal	A	196	60
	B	36	43
		Avg.	52
Reduced by 20%	A	36	45
	B	36	30
		Avg.	38

Photographs were taken of the freeze-thaw beams and are on file in Technical Services.

X-RAY POWDER DIFFRACTOMETRY OF SET-45 (REGULAR WITH AGGREGATE REMOVED)

As submitted to the Petrographic Laboratory, the samples of hardened Set-45 were a series of four, 2-inch cubes of hardened material which was composed of the product fabricated without the silica sand aggregate. The cube specimens were made in the Technical Services Physical Testing Laboratory at 23°C and with individual cubes stored at 23°C in air, 23°C in moist air, and air dried at 50°C and 100°C, respectively. Samples were to be transmitted to the Petrographic Laboratory according to the following schedule:

Test Age	23°C Air	23°C Wet	50°C Air	100°C Air
1 Day	X	X	X	X
2 Days	-	-	X	X
7 Days	X	X	-	-
28 Days	X	X	-	-

Similar cube specimens were to be produced by Ontario Hydro from the same material used to produce the specimens used at Master Builders. The product was formulated without the silica sand.

The following results are based only on interpretation of the x-ray powder diffraction patterns produced according to the above schedule.

SAMPLE PREPARATION AND METHODS

According to the schedule, the samples were submitted to the Petrographic Laboratory where a small portion of each cube, sufficient for the x-ray powder diffraction analysis, was chipped off the bulk cube sample. The bulk samples were immediately returned to their respective thermal and moisture conditions in the Technical Services Physical Testing Laboratory. The chipped portions of the cube were then ground in a mortar and pestle and passed through a U.S. Standard No. 170 sieve. A portion of the powder was back-packed into an x-ray powder diffraction specimen holder according to our standard procedure. The samples were then run in the x-ray powder diffractometer to produce the diffractograms used in the analyses.

Continued . . .

mixes were fabricated with added quartzose pea gravel. This was the last portion of the study under the subject work order.

The identification, water content of the respective mixes, relative dynamic moduli, number of cylces, and weight loss of the individual beams were submitted on paper tags with each of the beams. This information is in the following table:

TABLE I

I.D.	Pea Gravel	Water	RDM	Cycles	Wt. Loss
1B	Neat	9.98%	56%	136	-.2 lb.
2B	Neat	8.30%	46%	66	- 0 lb.
3A	Neat	6.65%	41%	36	- 0 lb.
4A	Yes	9.98%	50%	66	-.2 lb.
5B	Yes	8.30%	43%	36	- 0 lb.
6B	Yes	6.65%	30%	36	- 0 lb.

SAMPLE PREPARATION AND METHODS

A 1 x 3 x 4 inch slab was cut from each of the submitted beams with the cut surfaces oriented perpendicular to the long axis of each 3 x 4 x 16 inch beam. The cut surfaces of each specimen were prepared for examination by lapping with progressively finer abrasive grits according to our standard procedure and the slabs were then examined microscopically.

RESULTS

Sample 1B:

The specimen was composed of the neat product and exhibited the most obvious segregation of all the samples. The top 1/4 inch of the slab adjacent to the finished surface was primarily composed of very fine grained aggregate, fly ash, and paste with very little of the more coarse fractions of the natural aggregate of the product present in this surficial zone. Below this zone, the mortar appeared to be more harsh than is typical of the product. This harshness was probably a result of the segregation. Thin

VOLUME CHANGE, % INCHES

CRD-C 621-82B*

	72°F		90°F	
	A	B	A	B
1 Day	-.13	+.02	-.38	-.28
3 Day	-.13	+.02	-.38	-.28
7 Day	-.13	+.02	-.44	-.27
14 Day	-.17	+.03	-.44	-.27
21 Day	-.19	0	-.44	-.27
28 Day	-.19	0	-.44	-.27

*Specimens were cured using wet rags half the height of the apparatus and sealed in a plastic bag for duration of the test.

SET-45 HOT WEATHER FORMULA

MIX DATA

	Mix I	Mix II
% Water	8.6	8.6
Water temp. (°F)	72	72
Material temp. (°F)	72	72
As mixed temp. (°F)	72	72
Curing temp. (°F)	72	90
Unit weight, lbs./ft.^{3}	135.6	No Test
Yield, ft.^{3}/bag	.40	No Test
Air content, %	5.9	No Test

COMPRESSIVE STRENGTH* (AVG. PSI)**

	72°F	90°F
2 Hour	1310	1930
3 Hour	2495	4525
6 Hour	3985	4895
9 Hour	5585	5670
12 Hour	6685	5965
1 Day	7475	6440
3 Day	8400	7135
7 Day	8690	8025
28 Day	9435	10150

* Specimens were cured in their molds with cover plates for the duration of the test.

**Average of three specimens each.

W.O. 83-590 M

VOLUME CHANGE
CRD-C 621

	32°F		50°F		70°F	
Days	A	B	A	B	A	B
1	+.05	+.03	-.07	+.02	+.05	+.02
3	+.05	+.03	-.08	+.01	+.05	+.02
7	+.05	+.03	-.08	+.01	+.05	+.03
14	+.05	+.03	-.12	-.01	+.05	+.03
21	+.05	+.03	-.12	-.01	+.05	+.02
28	+.05	+.03	-.12	-.01	+.03	+.02

NOTE: No curing.

TIME OF SET, VICAT
(HRS:MIN.)

	32°F	50°F	70°F
Initial	0:37	0:24	0:11
Final	0:48	0:29	0:15

W.O. 83-590 M

RAPID FREEZING AND THAWING
ASTM C 666, PROCEDURE A

Specimens	Cycles	Durability Factor	Weight Change, Lbs.
A	300	72	+0.1
B	300	68	0
C	300	72	+0.1
Average	300	71	+0.1

NOTE: The specimens were mixed at 70°F and stored in laboratory air for 14 days prior to testing.

SCALING RESISTANCE
ASTM C 672

One set of specimens (3) were fabricated according to the ASTM procedure and then allowed to air cure in the laboratory 14 days prior to testing.

	Cycles					
Specimens	5	10	15	20	25	30
$NaCl_2$	0	0	0	0	0	0
$CaCl_2$	0	0	0	0	0	0
50/50 $NaCl_2/CaCl_2$	0	0	0	0	0	0

There was no evidence of scaling when the subject material was exposed to the three deicing salts.

W.O. 83-590 M

MIX DATA

	32°F*	50°F	70°F
% Water	8.3	8.3	8.3
Water temp. (°F)	33	40	65
Material temp. (°F)	32	54	70
As mixed temp. (°F)	33	52	72
Consistency,			
Flow table (%)**	-	85	78
Unit weights, lbs./ft.^{3}	-	137.9	137.6
Yield, ft.^{3}/bag	-	.39	.39
Bleeding	None	None	None
Mixing time (min.)	3	3	1-1/2

* Material mixed at ambient temperature of 50°F then specimens placed in a freezer at 32°F for duration of test.

**Five drops of flow table.

COMPRESSIVE STRENGTH, AVG. PSI*

	32°F	50°F	70°F
1 Hour	42	854	6320
3 Hour	4355	5560	8675
6 Hour	6810	7735	8040
9 Hour	7215	8010	8260
12 Hour	**	7995	8335
1 Day	7175	7795	8315
3 Day	**	7955	8545
7 Day	8300	6060	9585
28 Day	**	8960	11010

* Average of three specimens each.

**Not made due to limited space in the freezer.

NOTE: Specimens were stored in their molds without coverplates for 24 hours, then placed in a sealed gallon can for duration of test.

COMPRESSIVE STRENGTH TESTS

Sample No. Core	Size	Load	psi	Corrected psi*
3 - Neat	7.75" x 3.875"	47,300	4012	4012
4 - Pea Gravel	5" x 3.875"	17,400	1476	1380

*Includes 1/d correction factor

PETROGRAPHIC PREPARATION AND PROCEDURES

A 2.5 cm thick (1") slice was taken from the center of each sample, with the cut surfaces oriented parallel to the rotational axes of the cores. The lengths of the cut samples were as follows:

TABLE II

Sample No.	Length, cm (In.)
1	5.1 (2)
2	4.5 (1-3/4)
3	10.8 (4-1/4)
4	10.8 (4-1/4)
5	10.8 (4-1/4)
6	7.6 (3)
7	6.5 (2-1/2)

Samples 4 and 6 were too friable for preparation. In an effort to facilitate preparation, they were impregnated with a two-part epoxy resin. The resin was allowed to cure. All seven samples were then lapped according to our standard procedure.

88-67
Continued . . .

W.O. 86-154 M

SET-45 (REGULAR)
NEAT
COMPRESSIVE STRENGTH, AVG. PSI

Age	2" Cubes	3" x 6" Cylinders		6" x 12" Cylinders	
1 Hour	4392	2599	59.2 %	3049	69.4 %
2 Hour	5833	2740	46.974 %	3340	57.26 %
1 Day	7788	3513	45.1 %	3246	41.68 %
7 Day	8992	5042	56.07 %	4278	47.58 %
28 Day	10304	5538	53.75 %	4044	39.25 %
		261.094		235.17	
		AV	52.22 %	AV	51.034 %

SET-45 (REGULAR)
WITH PEA GRAVEL
(25 LBS. PEA GRAVEL/50 LBS. SET-45)

1 Hour	4592	2600	56.62 %	3050	66.42 %
2 Hour	6283	2521	40.12 %	3927	62.5 %
1 Day	7946	2720	34.23 %	4018	50.57 %
7 Day	8988	3322	36.96 %	5193	57.78 %
28 Day	8112	4469	55.09 %	5520	68.04 %
		223.02		305.31	
		AV	44.604 %	AV	61.062 %

Report No. 86-65 MC
February 20, 1986

SUBJECT: SEVEN CONCRETE CORES
ONTARIO-HYDRO
NORTHERN ONTARIO

Seven concrete cores, reportedly Set-45, were submitted to determine the aggregate soundness and overall soundness of the concrete. Air contents were also requested for the samples. The cores were also tested for compressive strength.

The cores were 9.8 cm (3-7/8") in diameter and were further identified as follows:

TABLE I

Sample No.	Length, cm (In.)	Markings
1	5.1 (2)	Top, 1400 Neat Set-45
2	4.5 (1-3/4)	Bottom, 3400 Neat Set-45
3	33 (13)	Middle of Sample, 5' Depth Total
4	16.5 (6-1/2)	Bottom, Center Mass
5	12.7 (5)	Outside Top
6	7.6 (3)	Center
7	6.4 (2-1/2)	Top

Samples 1-3 contained only fine aggregate and samples 4-7 contained coarse and fine aggregate. Prior to receipt by the Petrographic Laboratory, samples 3 and 4 had been trimmed and had undergone compressional testing.

Continued . . .

RAPID FREEZE-THAW
ASTM C 666, PROCEDURE A
70°F*

Specimen	Cycles	Relative Dynamic Modulus, %	Durability Factor	Weight Change, Lbs.
A	300	96	96	0
B	300	96	96	0
C	300	96	96	0
Average	300	96	96	0

RAPID FREEZE-THAW
ASTM C 666, PROCEDURE A
90°F*

Specimen	Cycles	Relative Dynamic Modulus, %	Durability Factor	Change, Lbs.
A	300	61	61	0
B	285	60	57	0
C	258	60	52	0
Average	281	60	57	0

*The specimens were mixed at 70°F and stored at these temperatures for 14 days with no curing prior to testing.

SCALING RESISTANCE
ASTM C 672

Two sets of specimens (3) were fabricated according to the ASTM procedure and then allowed to air cure at their respective temperatures (three specimens each at 70°F and 90°F) for 14 days prior to testing.

	Cycles					
70°F Specimens	5	10	15	20	25	50
$NaCl_2$	0	0	0	0	0	0
$CaCl_2$	0	0	0	0	0	0
50/50 $NaCl_2/CaCl_2$	0	0	0	0	0	0
90°F Specimens						
$NaCl_2$	0	0	0	0	0	0
$CaCl_2$	0	0	0	0	1	1
50/50 $NaCl_2/CaCl_2$	0	0	0	0	1	1

Rating	Condition of Surface
0	No scaling
1	Very slight scaling (1/8" depth maximum)
2	Slight to moderate scaling
3	Moderate (some coarse aggregate visible)
4	Moderate to severe scaling
5	Severe scaling (coarse aggregate visible over entire surface)

The samples were examined microscopically in accordance with ASTM C 856, the Recommended Practice for Petrographic Examination of Hardened Concrete. The air contents were determined microscopically by the modified point-count method at a magnification of 100X. Volumetric aggregate contents were also determined.

X-ray powder diffraction patterns were run on two of the samples to compare the mineralogy of the cementitious matrices. One sample (sample 3) was judged to have the best overall appearance. The other sample (sample 6) was judged to be in very poor condition. A portion of each sample was crushed and passed through a 230 mesh sieve. X-ray patterns were run on the -230 mesh sieve fraction.

PETROGRAPHIC EXAMINATION

TABLE III, AIR CONTENT

Sample No.	Air, % By Vol.*	Paste, % By Vol.*	Agg., % By Vol.*	Traverse Length, cm (In.)	Points Counted
1	17.94	14.24	67.81	189 (74.6)	1516
2	11.29	28.53	60.18	156 (61.5)	1248
3	13.75	27.84	58.41	252 (99.5)	2015
4	Sample 4 was too friable for accurate determinations				
5	11.18	10.95	77.87	260 (102)	2074
6	Sample 6 was too friable for accurate determinations				
7	12.55	15.96	71.49	210 (82.6)	1679

*The values derived should be regarded as estimates due to the poor condition of the prepared surfaces.

Sample 1:

The concrete was soft and the aggregate appeared uniformly distributed. The sample exhibited an extremely harsh texture due partially to what appeared to be poor consolidation. The sample contained 17.94% voids, by volume, as indicated in the above Table III. The voids were spherical and nonspherical and appeared free of internal secondary deposits.

Continued . . .

October 31, 1986

Master Builders
23700 Chagrin Boulevard
Cleveland, Ohio 44122

REFERENCE: STL File A86249x4(a)

MATERIAL TEST REPORT
ON SET 45 HOT WEATHER
LOT NO. X 2713V5

OBJECT

To test Set 45 for compressive strength, flexural strength, bond to concrete, time of set and freeze/thaw durability.

LABORATORY

The tests were performed in the Technical Services Laboratories of Master Builders under the supervision of Mr. Sam R. Jakabcic, Director, Operations for Solar Testing Laboratories, Inc., Garfield Heights, Ohio.

MIX PROPORTIONS

50	lbs. Set 45
4.15	lbs. Water
0.5	gal. Water

TEMPERATURES

Mortar	88° F
Water	90° F
Asmix	84° F
Ambient	90° F

RESULTS

1. Setting Time - Gillmore needle
   Initial - 47 minutes

2. Compressive Strength psi - 2" cubes
   Average of three (3) cubes per each age

2 HOUR	3 HOUR	6 HOUR	1 DAY	7 DAY
957	3400	4875	8575	10,413

3. Flexural Strength - Average psi

28 DAY
432

4. Bond to Concrete, 3 3/4" Core
   Tensile Strength - psi

28 DAY
473

5. Freeze/Thaw
   Durability Factor - 100 at 300 cycles

SOLAR TESTING LABORATORIES, INC.

Sam R. Jakabcic, C.E.T.
Director, Operations

SRJ/jag

October 31, 1986

Master Builders
23700 Chagrin Boulevard
Cleveland, Ohio 44122

REFERENCE: STL File A86249x4(a)

MATERIAL TEST REPORT
ON SET 45 REGULAR
LOT NO. X3358N6

OBJECT

To test Set 45 for compressive strength, flexural strength, bond to concrete, time of set and freeze/thaw durability.

LABORATORY

The tests were performed in the Technical Services Laboratories of Master Builders under the supervision of Mr. Sam R. Jakabcic, Director, Operations for Solar Testing Laboratories, Inc., Garfield Heights, Ohio.

MIX PROPORTIONS

50.0 lbs. Set 45
4.15 lbs. Water
0.5 gal. Water

TEMPERATURES

Mortar	71°F
Water	72°F
As Mixed	74°F
Ambient	71°F

RESULTS

1. Setting Time - Gillmore needle
   Initial - 34 minutes

2. Compressive Strength psi - 2" cubes
   Average of three (3) cubes per each age

1 HOUR	2 HOUR	3 HOUR	6 HOUR
2070	5366	6913	6983

1 DAY	7 DAY	28 DAY
8067	8463	8487

3. Flexural Strength - Average psi

28 DAY
540

4. Bond to Concrete, 3 3/4" Core
   Tensile Strength - psi

28 DAY
202

5. Freeze/Thaw, Modified
   Durability Factor - 100 at 300 cycles

   Specimens demolded at 2 hours, open air cured for 3 days, then tests were initiated.

SOLAR TESTING LABORATORIES, INC.

Sam R. Jakabcic

Sam R. Jakabcic, C.E.T.
Director, Operations

SRJ/jag

Report No. 86-65 MC
February 20, 1986

SUBJECT: SEVEN CONCRETE CORES
ONTARIO-HYDRO
NORTHERN ONTARIO

Seven concrete cores, reportedly Set-45, were submitted to determine the aggregate soundness and overall soundness of the concrete. Air contents were also requested for the samples. The cores were also tested for compressive strength.

The cores were 9.8 cm (3-7/8") in diameter and were further identified as follows:

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Samples 1-3 contained only fine aggregate and samples 4-7 contained coarse and fine aggregate. Prior to receipt by the Petrographic Laboratory, samples 3 and 4 had been trimmed and had undergone compressional testing.

88-67
Continued . . .

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*Includes 1/d correction factor

PETROGRAPHIC PREPARATION AND PROCEDURES

A 2.5 cm thick (1") slice was taken from the center of each sample, with the cut surfaces oriented parallel to the rotational axes of the cores. The lengths of the cut samples were as follows:

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Samples 4 and 6 were too friable for preparation. In an effort to facilitate preparation, they were impregnated with a two-part epoxy resin. The resin was allowed to cure. All seven samples were then lapped according to our standard procedure.

Continued . . .

The samples were examined microscopically in accordance with ASTM C 856, the Recommended Practice for Petrographic Examination of Hardened Concrete. The air contents were determined microscopically by the modified point-count method at a magnification of 100X. Volumetric aggregate contents were also determined.

X-ray powder diffraction patterns were run on two of the samples to compare the mineralogy of the cementitious matrices. One sample (sample 3) was judged to have the best overall appearance. The other sample (sample 6) was judged to be in very poor condition. A portion of each sample was crushed and passed through a 230 mesh sieve. X-ray patterns were run on the -230 mesh sieve fraction.

PETROGRAPHIC EXAMINATION

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Sample No.	Air, % By Vol.*	Paste, % By Vol.*	Agg., % By Vol.*	Traverse Length, cm (In.)	Points Counted
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7	12.55	15.96	71.49	210 (82.6)	1679

*The values derived should be regarded as estimates due to the poor condition of the prepared surfaces.

Sample 1:

The concrete was soft and the aggregate appeared uniformly distributed. The sample exhibited an extremely harsh texture due partially to what appeared to be poor consolidation. The sample contained 17.94% voids, by volume, as indicated in the above Table III. The voids were spherical and nonspherical and appeared free of internal secondary deposits.

Continued . . .

The cementitious matrix was white in color and soft. A moderate amount of white, clear, and black fly ash spheres was observed in the sample.

The aggregate was a fine aggregate composed of angular particles of quartz. The aggregate appeared volumetrically abundant relative to the bulk of the sample, imparting an extremely harsh texture to the sample.

Sample 2:

The sample was soft and the aggregate appeared uniformly distributed. The concrete exhibited an extremely harsh texture.

The sample contained 11.29% voids, by volume, as indicated in Table III above. Most of the voids were spherical with some non-spherical voids also present. The voids appeared free of internal secondary deposits.

The cement paste was white in color and soft. A moderate amount of clear, white, and black fly ash spheres was observed in the cementitious matrix.

The aggregate was a standard angular quartzose sand. The fine aggregate appeared to be volumetrically abundant relative to the bulk of the sample, imparting a harsh texture to the sample.

Sample 3:

The concrete was moderately hard and the aggregate appeared uniformly distributed. The sample contained 13.75% voids, by volume, as indicated in Table III above. Most of the voids were spherical and appeared free of internal secondary deposits.

The cementitious matrix was gray in color and moderately hard. A moderate amount of clear, white, and black fly ash spheres was observed in the sample. The primary mineral phase present in the cementitious matrix of the sample, as indicated by the x-ray pattern, was struvite, magnesium ammonium phosphate hydrate. Substantial amounts of magnesium oxide and quartz were also present. A small amount of dittmarite, magnesium ammonium orthophosphate monohydrate was present.

The aggregate was a standard angular quartzose sand. The sand appeared to be volumetrically abundant, imparting a slightly harsh texture to the sample.

Continued . . .

Samples 4 and 6:

The following description may be applied to both samples, based on the similarities observed. The concrete was extremely soft and friable. The friable nature of the samples precluded determination of the air content or aggregate distribution. An adequate prepared surface could not be obtained for examination.

The cementitious matrix was extremely soft, friable, and was white in color. The cementitious matrix was very highly water-absorptive. A moderate amount of clear, white, and black fly ash spheres was observed in the samples. The primary mineral component observed in the x-ray diffraction pattern of the cementitious matrix of sample 6 was struvite. Significant amounts of both magnesium oxide and quartz were also observed. No dittmarite was detected.

The coarse aggregate was a pea gravel composed of subrounded to rounded particles of quartz, quartzite, and friable quartz sandstone. The fine aggregate was a standard angular quartzose sand. The aggregates appeared to be volumetrically abundant relative to the bulk of the samples, imparting an extremely harsh texture to the concretes.

Samples 5 and 7:

Samples 5 and 7 had similar characteristics. The following description may be applied to both, except where noted.

The concrete was soft and the coarse aggregate was not uniformly distributed. The texture of the concrete was extremely harsh and friable.

Sample 5 exhibited 11.18% voids, by volume. Sample 7 exhibited 12.55% voids, by volume. The voids were spherical and nonspherical in shape and appeared free of internal secondary deposits.

The cementitious matrix was white in color, soft, and highly water-absorptive. A moderate amount of clear, white, and black fly ash spheres was observed in each sample.

The aggregates were similar to those described above for samples 4 and 6. The quartz sandstone particles were friable. The fine aggregate appeared to be volumetrically abundant, imparting a harsh texture to the concretes.

Continued . . .

DISCUSSION

Samples 1, 2, 4, 5, 6, and 7 exhibited evidence which suggests an excessively high water content for this type of product, based on the color, relative softness, and water-absorptivity. Sample 3 had a noticeably lower water:cement ratio. The absence of dittmarite in the x-ray pattern for sample 6 may indicate the water:cement ratio exceeded the recommended amount. One would expect to fine at least a small amount of dittmarite in a properly hydrated magnesium phosphate matrix.

It should also be noted these samples (1, 2, 4, 5, 6, and 7) contained what appeared to be volumetrically abundant aggregate, the amount and shape of which may have increased the water demand significantly, resulting in the observed excessive water:cement ratio. The quartz sandstones present in the coarse aggregate were friable and may have been abraded during the mixing, in essence changing the grading of the aggregate by increasing fines. This may have also resulted in an increased water demand.

This completes and closes Work Order 86-65 MC.

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KEY WORDS: ONTARIO-HYDRO; NORTHERN ONTARIO; CONCRETE CORES; SET-45; COMPRESSIVE STRENGTH; PETRO EXAM; X-RAY DIFF; LOW STRENGTH

PROJECT NO. KMHI6065